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Survey of Flue Gas Desulfurization Systems:
Lawrence Energy Center, Kansas Power and Light Co.

Interagency Energy/Environment R&D Program Report

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EPA-600/7-79-199b

August 1979

Survey of Flue Gas Desulfurization Systems: Lawrence Energy Center, Kansas Power and Light Co.

by

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Contract No. 68-02-2603
Task No. 24
Program Element No. EHE624

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

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ACKNOWLEDGMENT

This report was prepared under the direction of Mr. Timothy Devitt. The principal author was Mr. Bernard Laseke.

Mr. Norman Kaplan, EPA Project Officer, had primary responsibility within EPA for this project report. Information on plant design and operation was provided by the following members of the Kansas Power and Light Company: Mr. Kelley Green, Electric Production Manager, and Ron Teeter, Plant Superintendent, Lawrence Energy Center. Mr. A. J. Snider, Manager, Environmental Control, Combustion Engineering, Inc., also provided information on plant design and operation.

SUMMARY

The Lawrence Energy Center, a power generating station with a capacity of 625 MW (gross), is owned and operated by the Kansas Power and Light Company (KP&L) in Lawrence, Douglas County, Kansas. The station consists of five power generating units, the first of which was built in 1939. Lawrence 2 and 3 are oil/gas-fired peaking units rated at 30 and 60 MW. Lawrence 4 and 5 are multiple-fuel-fired units that now fire coal exclusively, and are rated at 125 and 400 MW.

Lawrence 4 and 5 are equipped with tail-end wet limestone scrubbing systems to meet air emission regulations of the Department of Health and Environment of the State of Kansas and the U.S. Environmental Protection Agency. Control of particulate and sulfur dioxide is accomplished by operational scrubbing systems consisting of two parallel two-stage scrubber modules, each of which includes a rectangular, variable-throat rod-deck venturi scrubber arranged in series with a spray tower absorber. Each system is also equipped with slurry-hold tanks, mist eliminators, and in-line reheaters, as well as isolation and bypass dampers that permit the modules to be bypassed during periods when oil or natural gas may be burned in the boilers. The two systems share a common limestone storage and preparation facility and waste-disposal facility.

The scrubbing systems, which were designed and supplied by Combustion Engineering, represent a second-generation design replacement of the limestone furnace-injection and tail-end scrubbing systems originally installed on these boilers in 1968 and 1971.

The original limestone furnace-injection and tail-end scrubbing system retrofitted on Lawrence 4 was started up in November 1968 and operated until mid-September 1976, when it was shut down to perform a scheduled turbine overhaul. During the course of this overhaul (2-1/2 months), the new scrubber modules were completed. The new system went into service in early January 1977. During the November 1968 to September 1976 period, the original injection system operated on coal-fired flue gas approximately 27,000 hours. To date, the new scrubbing system has accumulated approximately 10,000 hours of service time.

The original limestone furnace-injection and tail-end scrubbing system, installed as new equipment on Lawrence 5, started up in November 1971 and operated until March 20, 1978, when it was shut down to complete the tie-in of the new scrubbing system to the flue gas path. The new scrubber modules were erected directly behind the existing system, which remained in service during the construction period. Because the new system, which went into service on April 14, 1978, was designed to use the existing reaction tank, spray pumps, induced-draft fans, and stack, a 4-week outage was required to complete installation. The original injection system accumulated approximately 23,000 hours of service time on coal-fired flue gas.

Kansas Power and Light is now in the process of developing the Jeffrey Energy Center, a coal-fired power generating station with a 2880-MW (gross) capacity. This station is composed of four coal-fired units, having a capacity of 720 MW (gross). Scheduled for operation in October 1978, June 1980, 1982, and 1984, these units will fire low-sulfur Wyoming coal. The steam generators and emission control systems for Jeffrey 1 and 2 are designed and supplied by Combustion Engineering. The emission control systems include an overfire air system at the tangential-fired pulverized burners for nitrogen oxide abatement, electrostatic precipitators for particulate control, and limestone slurry spray towers for sulfur dioxide control. Because the Jeffrey scrubbing systems are similar in design to the Lawrence systems, the experience gained at Lawrence will facilitate the design and operation of the Jeffrey systems.

Table 1 summarizes data on the Lawrence facility and scrubbing systems.

TABLE 1. DATA SUMMARY: LAWRENCE 4 AND 5

Units	4 and 5
Gross rating, MW	
Lawrence 4	125
Lawrence 5	420
Net rating, MW	
Lawrence 4	115
Lawrence 5	400
Fuel	Coal
Average fuel characteristics	
Heating value, kJ/kg (Btu/lb)	23,260 (10,000)
Ash, percent	9.8
Moisture, percent	11.8
Sulfur, percent	0.55
FGD process	Limestone
FGD system supplier	Combustion Engineering
Status	Operational
Startup dates	
Lawrence 4	January 1977
Lawrence 5	April 1978
Design removal efficiency	
Particulate, percent	98.9
Sulfur dioxide, percent	
Lawrence 4	73
Lawrence 5	52
Water loop	Closed
Sludge disposal	Unstabilized sludge disposed in an onsite pond

SECTION 1
INTRODUCTION

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has initiated a study to evaluate the performance characteristics and reliability of flue gas desulfurization (FGD) systems operating on coal-fired utility boilers in the United States.

This report, one of a series on such systems, covers the Lawrence Energy Center of the Kansas Power and Light Company (KP&L). It includes pertinent process design and operating data, a description of major startup and operational problems and solutions, and atmospheric-emission data.

This report is based on information obtained during and after a plant inspection that KP&L conducted for PEDCo Environmental personnel on June 8, 1977. The information presented in this report is current as of October 1978.

Section 2 provides data on facility design and operation; Section 3 provides background information, as well as a detailed description and design features of the air quality control systems; Section 4 describes and analyzes the operation and performance of the air quality control systems. Appendices A, B, and C contain details of plant and system operation and photos of the installation.

SECTION 2
FACILITY DESCRIPTION

The Lawrence Energy Center, a power generating station with a capacity of 625 MW (gross), is owned and operated by KP&L. Located in Douglas County, the station is situated in a lightly-industrialized area on the outskirts of Lawrence, a town of about 47,000 people, near the Kansas River.

The station consists of five power generating units. The first, Lawrence 1, was built in 1939. This 10-MW turbine is powered by extraction steam from Lawrence 5. Lawrence 2 and 3, oil/gas-fired units rated at 30 and 60 MW, were originally placed in service in 1950 and 1956, and operate as peaking units. Lawrence 4, rated at 125 MW, and Lawrence 5, rated at 400 MW, are multiple-fuel-fired units that now fire pulverized coal exclusively. In service since 1959 and 1971, respectively, they currently operate as cyclic-load units.

The steam generators for Lawrence 4 and 5 are balanced-draft, tangential-fired, multiple-fuel-burning units supplied by Combustion Engineering. Lawrence 5 produces 1272 Mg (2,805,000 lb) per hour of superheat steam at 540°C (1005°F) and 18.1 MPa (2620 psi) and reheat steam at 540°C (1005°F). Figure 1 presents a view of the Lawrence 5 steam generator.

Although they were designed to burn pulverized coal, oil, and/or gas in any combination, both units are now fueled exclusively by a low-sulfur subbituminous grade of coal, which originates from mines located in Medicine Bow in the southeast section of Wyoming. This coal contains on the average 0.5 percent sulfur, 10 percent ash, and 12 percent moisture, and has a heating value of 23,260 kJ/kg (10,000 Btu/lb). At full load, Lawrence 4 and Lawrence 5 consume approximately 45 Mg (50 tons) and 145 Mg (150 tons) of coal per hour, respectively.

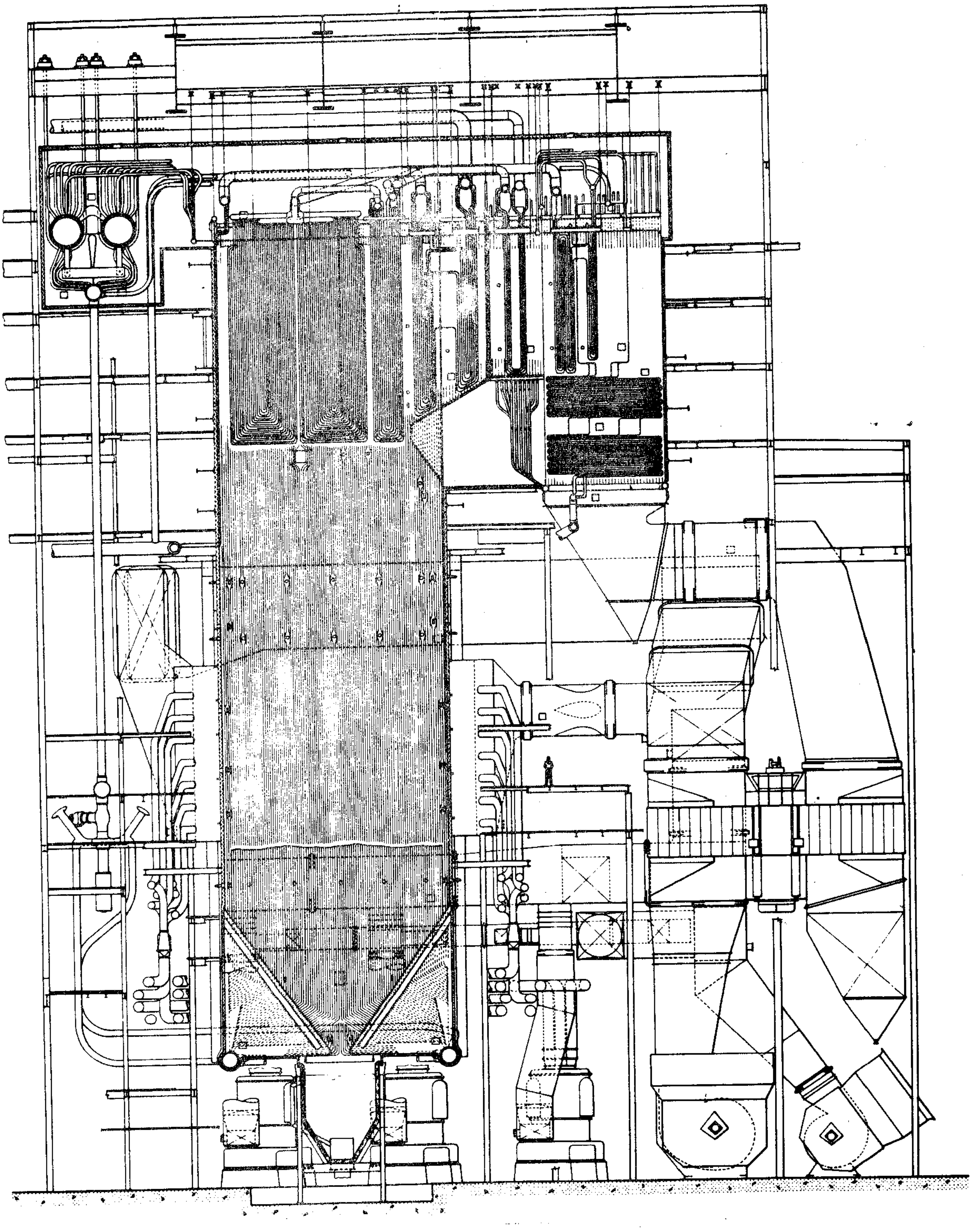

Figure 1. View of the Lawrence 5
Combustion Engineering steam generator.

To meet air emission regulations of the Department of Health and Environment of the State of Kansas and the U.S. EPA, each unit is equipped with a tail-end wet limestone scrubbing system consisting of two parallel scrubber modules for the control of particulate and sulfur dioxide. These Combustion Engineering systems represent a second-generation design replacement of the limestone furnace-injection systems originally installed on these units in 1968 and 1971.

Maximum particulate emissions allowable under regulations of the Department of Health and Environment of the State of Kansas are 43 ng/J (0.1 lb/10^6 Btu) of heat input to the boiler. Actual particulate emissions, as measured by the system supplier and utility during performance tests conducted on Lawrence 4, are 34 ng/J (0.08 lb/10^6 Btu) of heat input to the boiler.

Maximum sulfur dioxide emissions allowable under regulations of the Department of Health and Environment of the State of Kansas are 129 ng/J (0.3 lb/10^6 Btu) of heat input to the boiler for Lawrence 4 and 215 ng/J (0.5 lb/10^6 Btu) of heat input to the boiler for Lawrence 5. Actual sulfur dioxide emissions, as measured by the system supplier and the utility during performance tests conducted on Lawrence 4, are 6.5 to 13 ng/J (0.015 to 0.03 lb/10^6 Btu) of heat input to the boiler.

Table 2 summarizes data on plant design and operation.

TABLE 2. DESIGN, OPERATION, AND EMISSION DATA: LAWRENCE 4 AND 5

Description	Lawrence 4	Lawrence 5
Generating capacity, MW		
Gross	125[a]	400
Net with scrubbing	115[a]	375
Maximum coal consumption, Mg/h (tons/h)		145 (150)
Maximum heat input, GJ/h (10^6 Btu/h)	1,055 (1,000)	3,376 (3,200)
Maximum flue gas rate, m^3/s (10^3 acfm)	190 (403,000)	600 (1,271,000)
Flue gas temperature, °C (°F)	138 (280)	149 (300)
Unit heat rate, kJ/net kWh (Btu/net kWh)	10,900 (10,300)	10,900 (10,300)
Unit capacity factor, percent (1977)	55-60	55-60
Emission control		
Particulate	Rod-deck venturi scrubbers	Rod-deck venturi scrubbers
Sulfur dioxide	Spray tower absorbers	Spray tower absorbers
Particulate emission rate		
Allowable, ng/J (lb/10^6 Btu)	43 (0.1)	43 (0.1)
Actual, ng/J (lb/10^6 Btu)	34 (0.08)	
Sulfur dioxide emission rate		
Allowable, ng/J (lb/10^6 Btu)	129 (0.3)	215 (0.5)
Actual, ng/J (lb/10^6 Btu)	6.5-13 (0.015-0.08)	

[a] Gross output of Lawrence 4 is as high as 143 MW when natural gas is burned in the boiler. This value decreases to 125 MW when coal and natural gas are burned in the boiler.

[b] Retrofitting the boiler with the limestone-injection scrubbing system in 1968 reduced the unit's net output to 115 MW.

SECTION 3
FLUE GAS DESULFURIZATION SYSTEM

BACKGROUND INFORMATION

Approach

In 1967 KP&L decided to expand the generating capacity of Lawrence Energy Center by adding a 400-MW unit. At that time KP&L was still classified as a gas-fired utility, even though 65 percent of its steam generators were equipped to fire pulverized coal. Because of the increasing potential interruptions in gas supply, KP&L designed Lawrence 5 to burn primarily coal, supplemented by natural gas and fuel oil.

When planning this addition, KP&L assumed that some ambient and/or emission regulations for particulate and sulfur dioxide would be in effect by the commercial startup date of Lawrence 5 (November 1971). This assumption, plus the availability of high-sulfur Kansas coal, prompted the decision to install, as original equipment, facilities to remove particulate and sulfur dioxide from the flue gas of Lawrence 5.

The emission-control strategy selected for Lawrence 5 was a limestone wet scrubbing system. This furnace-injection, tail-end system was developed by Combustion Engineering. This steam generator supplier has been committed since 1964 to an intensive research and development program based on work done earlier in the field of oil and coal corrosion and stack gas emission control.

Lacking full-scale scrubbing experience on utility coal-fired steam generators, KP&L decided to retrofit a similar but smaller system on Lawrence 4, an existing 125-MW unit, to obtain valuable design and operating experience prior to startup of the larger unit. Construction on this scrubber system began in March 1968, and initial startup occurred in November 1968. Construction of the Lawrence 5 boiler and scrubbing system also commenced in March 1968 and proceeded simultaneously with the retrofit work on Lawrence 4. Initial operation of Lawrence 5, including the emission control system, occurred in March 1971. Shakedown and debugging of the equipment was completed, and commercial operations began in November 1971.

Design

The original scrubbing systems installed on Lawrence 4 and 5 were identical in basic design and operation. Each system included facilities for pulverizing limestone and then injecting it into the boiler furnace chamber for calcination. The flue gas transported the calcined limestone and fly ash to the scrubber modules for particulate and sulfur dioxide scrubbing. The cleaned gases then passed through a set of mist eliminators, reheaters, and induced-draft fans before being discharged through the stacks to the atmosphere.

The Lawrence 4 scrubbing system consisted of two scrubber modules. The Lawrence 5 scrubbing system was originally equipped with six, and two more were added soon after startup. All the modules were identical in size; each was designed to handle approximately 70 m^3/s (150,000 scfm) of flue gas. Each module had a single marble bed of 1.9-cm (0.75-in.) diameter Pyrex glass marbles. The beds were approximately 9 cm (3.5 in.) thick and included overflow pots for drainage of spent slurry into the receiving recirculation tanks.

Each module was also equipped with mist eliminators and reheaters. Two stages of horizontal, chevron-type mist eliminators were situated approximately 1.5 m (4.5 ft) above the marble bed. Four rows of carbon steel finned-tube reheat bundles were situated approximately 6.5 m (20 ft) above the second mist eliminator stage. The mist eliminators were equipped with automatic retractable wash lances that sprayed pond return water under high pressure [0.7 MPa (100 psig)] 1 cycle each day. The reheaters were also equipped with a self-cleaning system in which high-pressure [0.65 to 0.80 MPa (80 to 100 psig)] compressed air was blown from lances for 3 minutes six times daily.

Each Lawrence 4 module was connected through an induced-draft fan to a separate 36-m (120-ft) carbon steel stack. The Lawrence 5 unit consists of eight modules discharging to two I.D. fans with separate stack connections to a common 114-m (375 ft) stack. Originally, all the modules were equipped with bypass ducts and hydraulic seal dampers, but extensive corrosion and plugging necessitated their removal from both modules of Lawrence 4. Figure 2 provides a simplified schematic of the Lawrence 5 scrubbing system arrangement.

Spent scrubbing slurry from each system was collected in a separate, external recirculation tank, where a 35-minute retention time permitted completion of chemical reactions and where pond return water and discharge of spent slurry were added.

The waste streams from both systems were discharged to onsite, unlined settling ponds for ultimate disposal of waste solids. The scrubbing wastes were collected in three ponds with areas of 16,000 m^2 (4 acres), 65,000 m^2 (16 acres), and 113,000 m^2 (28 acres). Clarified supernatant from these ponds was returned to the systems for further use after selective staging.

Figure 3 is a simplified process flow diagram of the limestone furnace-injection and tail-end scrubbing system installed and operated at Lawrence. Design parameters and operating conditions for the Lawrence scrubbing systems are summarized in Tables 3, 4, 5, 6, and 7.

Performance

Problems and Solutions--

As indicated above, the Lawrence 4 scrubbing system was placed in service in March 1968, approximately 3 years before that of Lawrence 5. Although the configuration of these original

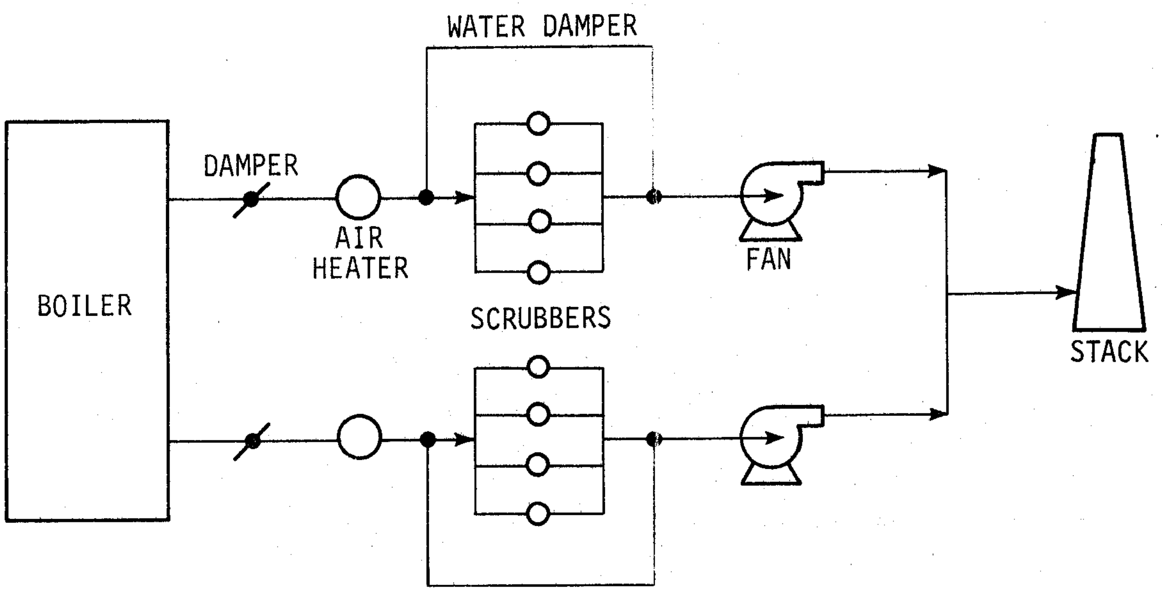

Figure 2. Scrubber train schematic for Lawrence Unit 5.

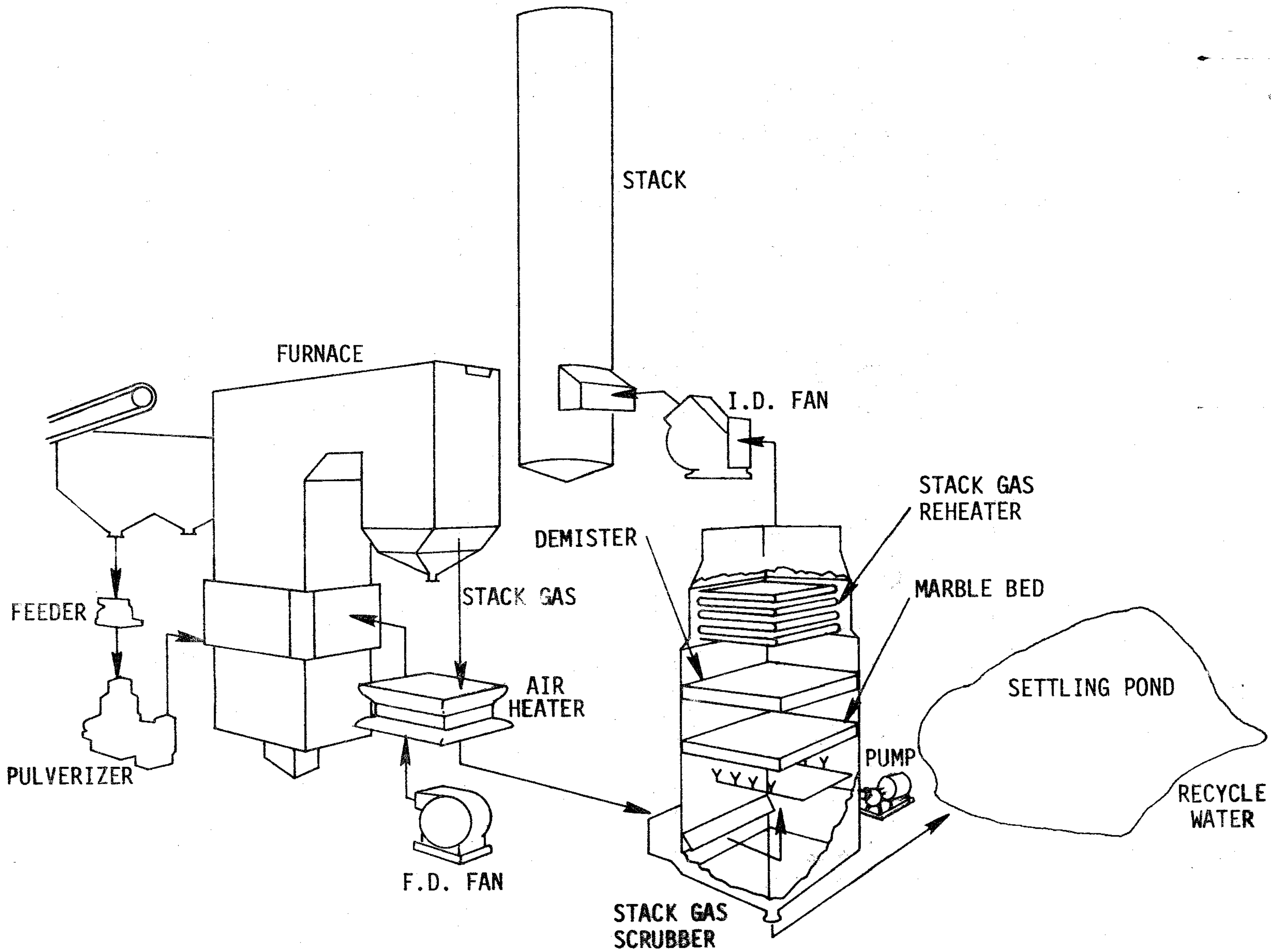

Figure 3. Simplified process flow diagram of the Lawrence limestone-injection and tail-end scrubbing system.

TABLE 3. SUMMARY OF DATA: SCRUBBER MODULES

Category	Lawrence 4	Lawrence 5
Number of modules	2	8
Type	Marble bed	
Capacity, m^3/s (scfm)	70 (150,000)	
Liquid-to-gas ratio (L/G), liters/m^3 (gal/10^3 acf)	2.9 (22)	
Superficial gas velocity, m/s (ft/s)	2 (6.5)	
Equipment internals		
Number of beds	1	
Bed packing thickness, cm (in.)	9 (3.5)	
Marble sphere diameter, cm (in.)	1.9 (0.75)	
Materials of construction		
Shell	Flake-glass-lined carbon steel	
Internal supports	316L SS	
Drain pots	316L SS	

TABLE 4. SUMMARY OF DATA: MIST ELIMINATORS

Type	Chevron
Configuration (relative to gas flow)	Horizontal
Shape	V-shape, sharp angle, 90-deg bend
Number of stages	2
Number of passes	2
Distance between stages, m (ft)	0.3 (1.0)
Pressure drop, kPa (in. H_2O)	0.25 (1.0)
Materials of construction	FRP

TABLE 5. SUMMARY OF DATA: REHEATERS

Type	Indirect, in-line
Heating medium	Hot water
Heating medium source	Deaerator
Materials of construction	Carbon steel
Heat input, GJ/h (10^6 Btu/h)	
Lawrence 4	21.1 (20)
Lawrence 5	84.4 (80)
ΔT, °C (°F)	17 (30)

TABLE 6. SUMMARY OF DATA: RECYCLE TANKS

Item	Lawrence 4	Lawrence 5
Total number of tanks	1	1
Retention time,[a] minutes	40	30
pH	9.5-10	9.5-10
Solids concentration, %	8.5-9.5	8.5-9.5

[a] At full-load conditions.

TABLE 7. SUMMARY OF DATA: PRESSURE DROP

Component	Pressure drop, kPa (in. H_2O)
Scrubber module	2.0 (8.0)
Mist eliminator and reheater	0.25 (1.0)
Duct work	0.25 (1.0)
Total	2.5 (10.0)

systems was fairly simple, many operating problems and design inadequacies were encountered. Since the purpose of installing the Lawrence 4 scrubbing system was to gain design and operating experience, all design modifications and other corrective action were first implemented on this system. Successful results were then utilized on Lawrence 5.*

Nearly all of the problems that were encountered during and following startup were due to improper control of process chemistry. In the injection process, it was difficult to achieve satisfactory control of the limestone calcination as well as the amount of lime/limestone carried in the flue gas to the tail-end scrubbers. This problem was complicated further when the boiler operated as a cyclic-load unit and fired a variable combination of coal, natural gas, and oil.

Figure 4 illustrates the configuration of each of the Lawrence 4 modules when the system started operating in 1968. This design presented many operating problems, including (1) scale buildup and solids deposition on the hot gas inlet duct; (2) erosion of the scrubber walls; (3) corrosion of scrubber internals; (4) plugging and scaling of drain lines, tanks, pumps, marble bed, mist eliminator, and reheater; (5) scale buildup on induced-draft fan rotors, resulting in fan imbalance and vibration; and (6) dead burning of limestone in the furnace and the dropout of the lime with the ash in the bottom of the scrubbers.

After the first few months of operation, the scrubbers were modified as follows: (see Figure 5).

1. Soot blowers were added in the gas-inlet duct and under the reheater bundle to minimize solids deposition problems.

---

*Lawrence 5 experienced one major problem that was not encountered with Lawrence [illegible] severe gas distribution problems to and through the marble-bed scrubber modules. This complicated scrubbing operations on Lawrence 5 and, as a result, Lawrence 4 achieved a higher level of operating efficiency.

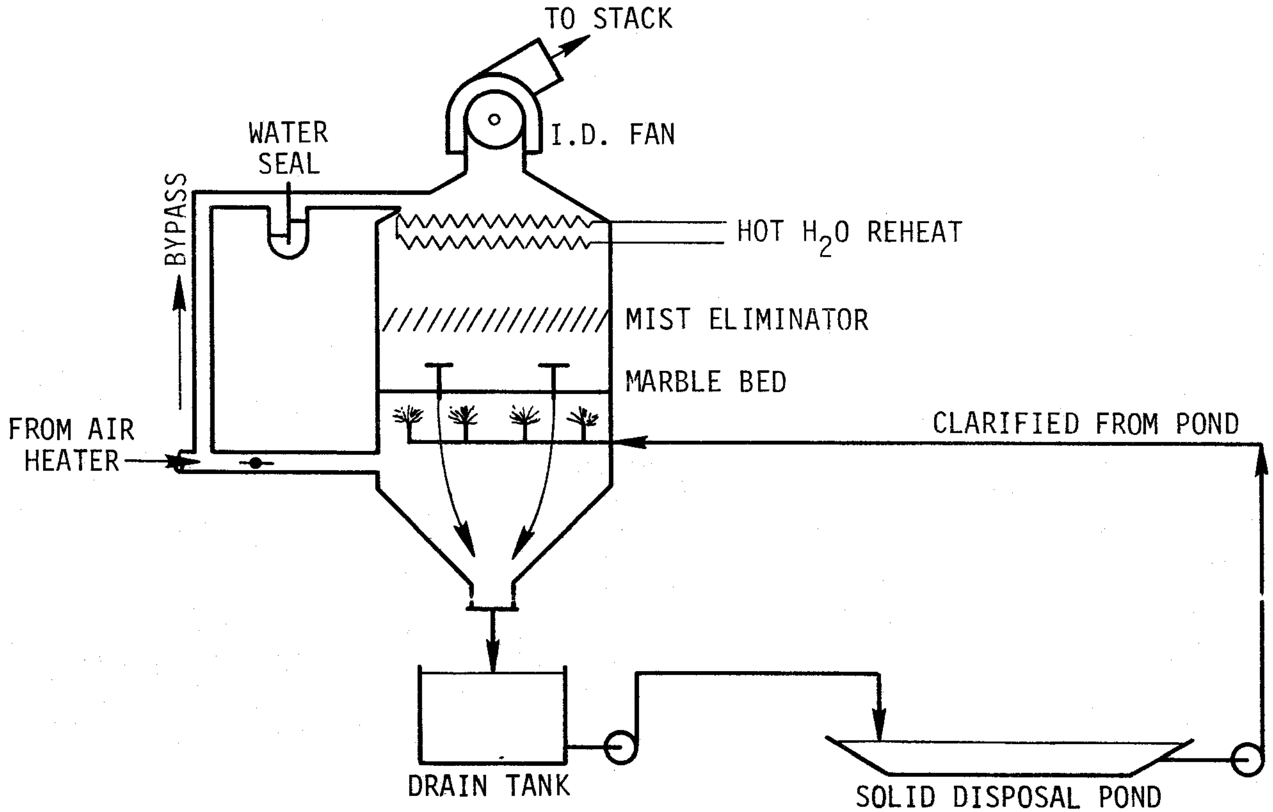

Figure 4. Lawrence 4 flow diagram: December 1968.

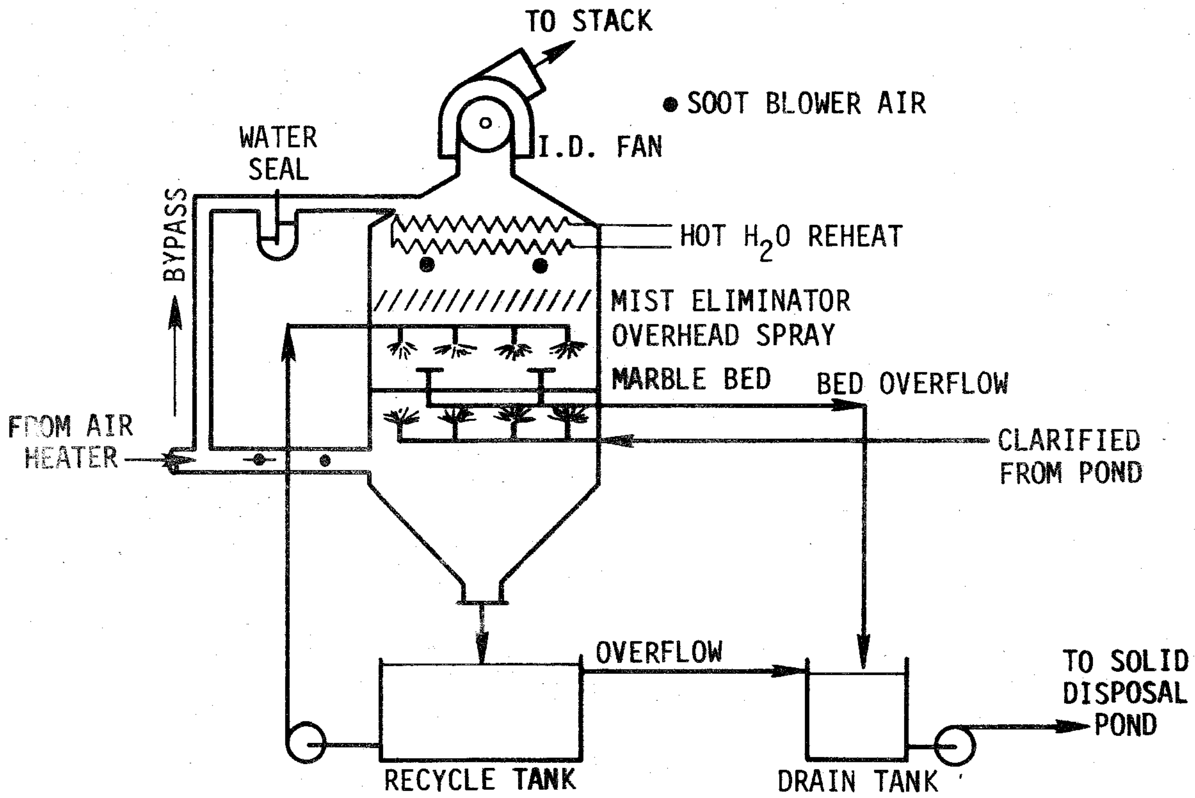

Figure 5. Lawrence 4 flow diagram: October 1969.

2. The freeboard distance of the mist eliminators was increased to reduce solids carryover from the spray zone.

3. Overflow liquor from the pots was directed to the pond.

4. A larger recycle tank and pump were installed to collect and recirculate the spent slurry back to the marble bed.

5. A new type of spray nozzle was installed.

6. The bottom section of the scrubber tanks was lined with gunite.

7. Hydraulic variable-speed drives were installed on all the fans.

Most of the problems were reduced but not eliminated by these modifications. For further reduction of corrosion, erosion, scaling, and solids deposition problems, additional modifications were made during the summer of 1970. The resulting scrubber configuration is illustrated in Figure 6. These major revisions included:

1. The interiors of the modules were sandblasted and coated with flake-glass lining.

2. All internal steel pipes were replaced with plastic and fiberglass piping.

3. The stainless steel mist eliminators were replaced with fiberglass components.

4. A ladder vane was added under the marble beds to improve gas flow distribution.

5. The pot overflow drain piping was modified to permit liquor return to the recycle tank.

6. The original copper fin tubes on the reheater coils were replaced with a carbon steel fin tube coil. Because of the close spacing of the fins on the copper tubes, the reheaters plugged easily and the fins were flattened by the soot-blower jets.

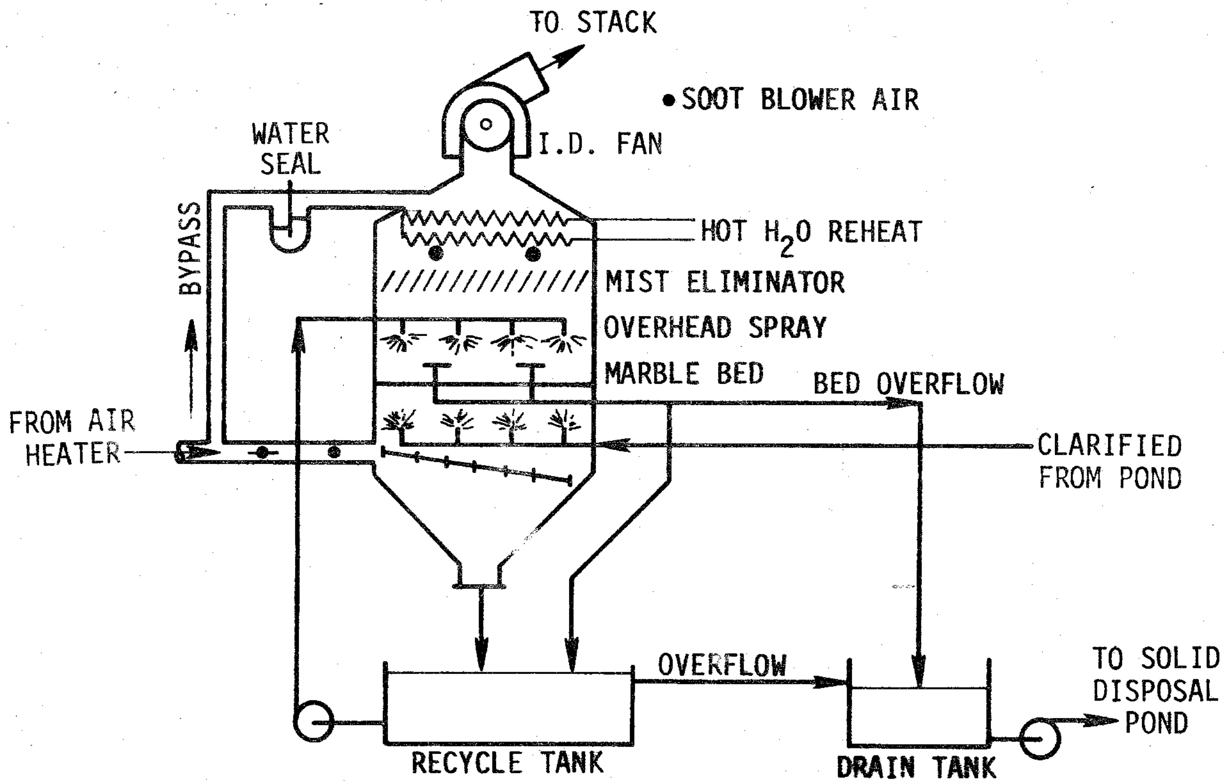

Figure 6. Lawrence 4 flow diagram: October 1970.

Solids deposition in the mist eliminators continued to be a serious problem, necessitating manual washing every other night to maintain the required unit output.

In the summer of 1972, the modules were modified to operate using a high-solid slurry-crystallization process to control sulfate saturation and subsequent scale development. These latest major modifications, shown in Figure 7, included the enlargement of the liquor-recirculation tank as well as the replacement of piping, nozzles, pumps, and agitators. The mist eliminators were replaced with a new two-bank fiberglass unit fitted with high-pressure wash water lances.

Even though this last series of major modifications resulted in a dramatic improvement in overall performance, some chemical and mechanical problems were still encountered, including isolated corrosion, expansion-joint failure, solids deposition in the mist eliminators, erosion and premature failure of slurry pumps, and valve failures. Load demand at this station allowed both units to be reduced to half-load each night so necessary and preventive maintenance to combat these latter problems could be accomplished without forced outages. Maintenance requirements declined to two 8-h shifts weekly of manual cleaning per module.

In 1974 KP&L completed negotiations for a low-sulfur coal supply from southeast Wyoming (Medicine Bow), and the high-sulfur Kansas coal was completely phased out by late spring of 1975. Subsequent operation of the scrubbing systems was more efficient and economical because of the reduced sulfur removal requirements and the alkaline components of the fly ash. This latter factor substantially reduced the amount of limestone required for scrubbing since the alkaline species were already present in the slurry from fly ash collected in the modules. As a result, normal maintenance requirements were halved to two 4-h shifts of manual cleaning per module.

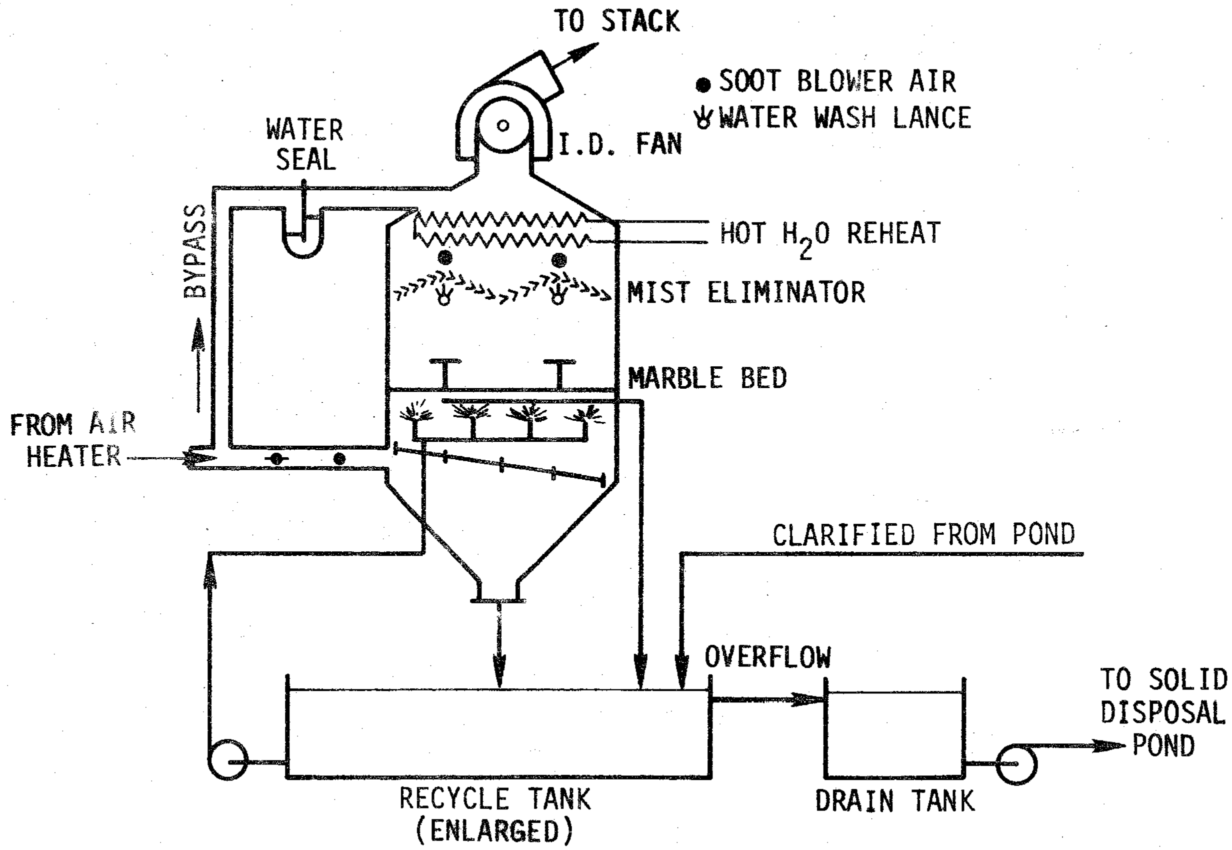

Figure 7. Lawrence 4 flow diagram: October 1972.

Removal Efficiency--

Both Lawrence scrubbing systems were designed to remove 99.3 percent of the inlet particulate and 65 percent of the inlet sulfur dioxide when high-sulfur Kansas coal was combusted in the boilers. Actual removal values indicated that these goals were attained or exceeded. Sulfur dioxide removal efficiencies as high as 85 percent were achieved over short periods, but only at the expense of an accelerated rate of scale formation in the modules, which ultimately required shutdown for cleaning and reduced system availability.

Future Development

In 1976, having achieved success with scrubbing operations at Lawrence, KP&L decided to replace both systems with a second-generation scrubbing design developed by Combustion Engineering. There were several reasons for this decision:

1. During modifications and revisions in the scrubber modules, Lawrence operated at deleterious corrosion levels, which caused widespread deterioration of the modules and ancillary equipment and necessitated either the installation of new systems or the implementation of an alternative control strategy (low-sulfur coal combustion and electrostatic precipitators).

2. Lawrence 4 redesign was committed at approximately the same time that the decision was made concerning the Jeffrey Energy Center's emission control strategy. The company decided to incorporate the use of wet particulate scrubbers rather than an electrostatic precipitator, primarily because resistivity of the Medicine Bow coal fly ash is very high and would require large ESP's for attainment of 99 percent removal. This would have necessitated relocation of other plant equipment and, thus, was deemed impractical.

3. Lawrence 5 redesign was committed soon afterwards. KP&L elected to employ basically the same strategy as that developed for Lawrence 4. Many of the components of Lawrence 5, unlike Lawrence 4, had not been destroyed during initial phases of operation; the fact that the air quality control system's original reaction tank,

spray-pump system, induced-draft fans, and stack could all be employed in the redesign gave this plan a decided economic, spatial, and temporal advantage over alternative strategies.

4. With the exception of the method of particulate collection, the emission control strategies developed for Lawrence and Jeffrey Energy Centers are basically the same. The installation of these systems at Lawrence would provide valuable design and operating experience for future, larger-scale applications at Jeffrey. This would offer the added benefit that any potentially costly modifications could be made prior to startup.

PROCESS DESCRIPTION

The limestone scrubbing systems now in service on Lawrence 4 and 5 are second-generation design units supplied and installed by Combustion Engineering. Basically, both systems encompass the same general equipment layout, consisting of a common limestone storage and preparation facility, two rod-deck venturi scrubbers and spray tower absorber modules, and a common waste disposal facility.

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The air quality control system at Lawrence 4 can be described in terms of three basic operations: (1) limestone handling and preparation, (2) gas treatment, and (3) waste solids disposal and pond water return.

Reagent Handling and Preparation

Limestone for the Lawrence scrubbing systems is trucked from quarries owned and operated by the N.R. Hamm Company, approximately 3 km (2 mi) north of the plant, and stored in an area situated directly behind the milling facility. It is received as

Removal Efficiency--

Both Lawrence scrubbing systems were designed to remove 99.3 percent of the inlet particulate and 65 percent of the inlet sulfur dioxide when high-sulfur Kansas coal was combusted in the boilers. Actual removal values indicated that these goals were attained or exceeded. Sulfur dioxide removal efficiencies as high as 85 percent were achieved over short periods, but only at the expense of an accelerated rate of scale formation in the modules, which ultimately required shutdown for cleaning and reduced system availability.

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1.9-cm (3/4-in.) rock (gravel size) containing 93 percent calcium carbonate, 6 percent silicas, and 1 percent magnesium carbonate.

After limestone from the storage area has been fed by bucket elevator to a storage hopper, a weigh feeder transfers it to the wet ball mill, where it is ground to an 80 percent minus 200 mesh particle size. The mill effluent, which is approximately a 60 percent solids slurry, is collected in a mill sump. From there, it is transferred by mill slurry pumps (two, one operational/one spare) to a classification system consisting of a scalping screen and collection tank. Slurry particles larger than 200 mesh are collected on the screen and returned to the mill for crushing. The slurry contained in the classification collection tank is transferred by additive transfer pumps to an agitated additive storage tank. Variable speed pumps (two, one operational/one spare) transfer the 60 percent solids slurry to a dilution tank, where it is diluted to 10 percent solids with makeup water (a blend of thickener overflow and pond return water) collected in the scrubbing system's recirculation tank. The 10 percent solids limestone slurry is transferred to the spray tower reaction tanks by additive feed pumps (four, two operational/two spare) at a rate of 3 liters/s (50 gpm) per module at full load.

As indicated above, the limestone handling and preparation facility is shared by both Lawrence 4 and 5 scrubbing systems. Figure 8 shows a simplified process flow diagram of the limestone handling and preparation facility.

Gas Treatment

Flue gas from the boiler passes through the existing air heater and is conveyed by new duct work to two unitized 50 percent capacity scrubber modules, each module consisting of a rectangular, variable-throat, rod-deck, venturi scrubber arranged in series with a spray tower absorber. Each module is equipped with two reaction tanks, mist eliminators, reheater, bypass duct, bypass

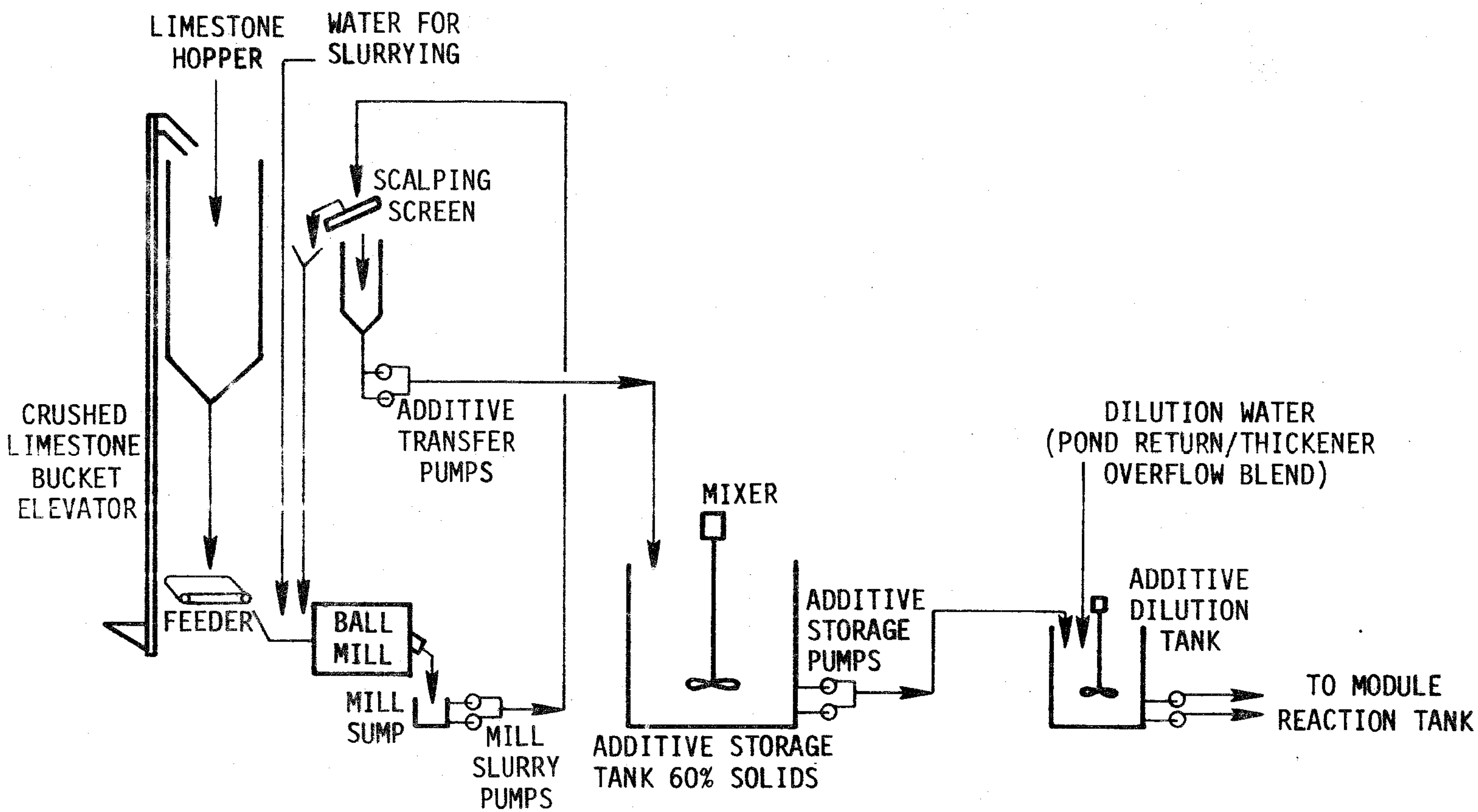

Figure 8. Lawrence 4 limestone preparation and handling system.

dampers, and isolation dampers. Bypass ducts make possible the bypass of the scrubber modules during periods when oil or natural gas is burned in the boiler.

Flue gas at 138°C (280°F) enters the scrubbing system at a rate of 190 m^3/s (403,000 acfm) through two parallel, rectangular, rod-deck venturi scrubbers, each comprised of a converging gas section and rod section. The converging gas section directs the flue gas downward to the rod-deck section, which measures 0.9 m by 7 m (3 ft by 23 ft) and consists of two staggered levels of rubber-coated fiberglass rods. The rods, which have an outer diameter of 16.8 cm (6.625 in.), are located on 33-cm (13-in.) centers. The vertical spacing between the two rows of rods is automatically controlled according to gas load in order to insure a constant gas-side pressure drop across the rod section.

A series of nonatomizing, fan-type spray nozzles located around the perimeter of the throat area continuously spray limestone slurry into the rod-deck scrubber, where an intimate gas-slurry contact occurs, which facilitates particulate and sulfur dioxide removal. Spent slurry from the rod section gravity feeds into a collection tank located directly below the venturi. This tank, which has a liquid capacity of 190,000 liters (50,100 gal), retains the slurry for approximately 14 min to allow for completion of chemical reactions. The slurry is recycled from the collection tank to the rod-deck scrubber by means of a slurry recirculation pump (one operational/one spare) at a rate of 227 liters/s (3600 gpm).

After passing through the rod-deck venturi, the flue gas makes one 90-degree turn as it approaches the spray tower and another 90-degree turn before passing upward through the spray tower at 165 m^3/s (349,000 acfm). The saturated gas, cooled to 52°C (124°F), flows upward through two levels of sprays in the open towers, where the gas is contacted by the slurry, which is sprayed countercurrent to the gas flow. The spray levels, each of which include four internal spray headers containing six spray nozzles each, are situated at approximately 3-m (10-ft) intervals above the inlet duct.

Spent slurry from each spray tower gravity feeds into a reaction tank located directly below the tower. The reaction tank, which has a liquid capacity of 262,000 liters (69,200 gal), retains the slurry for approximately 10 min for completion of chemical reactions and dissolution of fresh limestone additive. The slurry is then recycled to the spray tower by means of one slurry recirculation pump at a rate of 335 liters/s (5300 gpm).

Entrained droplets of moisture and slurry picked up by the flue gas stream are removed in a mist elimination section approximately 3 m (10 ft) above the spray zone in the spray towers. Each mist eliminator is an A-frame design comprised of a bulk entrainment separator followed by two stages of chevron vanes. Each is equipped with an intermittent, high-pressure, water-wash system which sprays blended makeup water on the top of the bulk entrainment separator and the bottom of the first mist-eliminator stage. Figure 9 shows the mist eliminator design used in the Lawrence scrubbing systems.

Following passage through the mist eliminators, the saturated gas stream is reheated by an in-line, carbon steel reheater. One such reheater, which consists of four rows of circumferential finned tubes arranged in a staggered fashion, is provided for each spray tower. The heating medium is hot water from the boiler feed water deaerator. Two half-track soot blowers located upstream of the reheaters provide compressed air every 4 hours of service to keep the reheaters clean. The reheaters boost the temperature of the gas stream approximately 11°C (20°F), after which it flows through the ducts leading to the induced-draft fans and stacks, which discharge it to the atmosphere.

<u>Waste-Solids Disposal and Pond Water Return</u>

Waste solids accumulated in the slurry circuits are effectively removed from the scrubbing system by a sequence of liquid

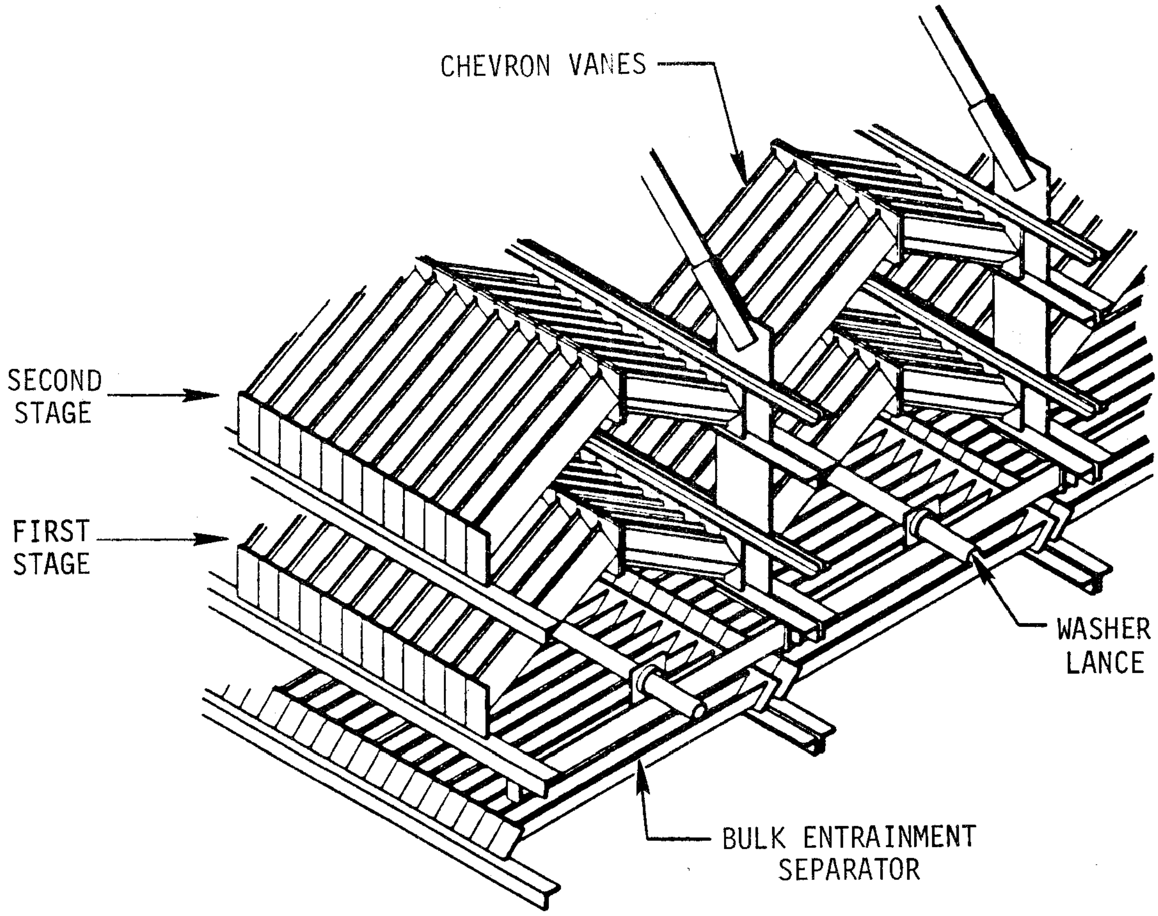

Figure 9. Diagram of the proprietary mist eliminator design used in the Lawrence scrubbing systems.

staging, forced oxidation, and thickening, which ultimately produces a 35 percent solids waste stream for disposal in ponds on the plant site. The supernatant from the ponds is recycled for additional use. Liquid staging is accomplished by the separate slurry-hold tanks provided for each rod-deck scrubber and spray tower absorber. The solids in the reaction tanks are controlled at the 5 percent level by bleeding slurry via gravity feed to the collection tanks. At full load, the reaction tank bleed stream discharges at a rate of approximately 2.5 liters/s (40 gpm) per module. The solids in the collection tanks are controlled at the 8 to 10 percent level by varying the flow of the effluent bleed pump.

Each collection tank is equipped with a forced oxidation system, which converts virtually all of the sulfite to sulfate by sparging air through the collection tanks at an air stoichiometry of 400 percent. This reduces the level of sulfite species in the scrubbing circuit, thus minimizing the likelihood that hard sulfate scale will develop in the scrubbers. Forced oxidation also improves the quality of the sludge because the oxidized wastes (gypsum) tend to settle out faster and set up harder than unoxidized wastes.

Each collection tank is also equipped with one effluent bleed pump which discharges the underflow to the system's thickener. The thickener concentrates the slurry to a 30 to 35 percent solids underflow, which is transferred to onsite sludge disposal ponds. Thickener overflow flows by gravity into a recirculation (surge) tank. Sludge disposal is provided by a network of three ponds with areas of 16,000 m^2 (4 acres), 65,000 m^2 (16 acres) and 113,000 m^2 (28 acres). Thickener overflow enters the 65,000-m^2 (16-acre) pond and overflows into the other two. The supernatant is returned to the process, where it is blended with thickener overflow in the recirculation tank. This blended water is used for mist eliminator wash, strainer wash, and maintaining liquid levels in the collection and reaction tanks.

Figure 10 shows a simplified process flow diagram of the Lawrence 4 scrubbing system.

Lawrence 5 Scrubbing System

The design of the Lawrence 5 scrubbing system is very similar to that of Lawrence 4 in that it contains two scrubbing modules, each consisting of a rod-deck scrubber in series with a spray tower absorber, to treat 100 percent of the flue gas from the steam generator. In addition, the system shares the limestone handling and preparation facilities and the sludge disposal ponds used by Lawrence 4. Several major features of Lawrence 5 are different, however, and these are summarized briefly in the following paragraphs.

Gas Conditions--

Medicine Bow coal is burned in both Lawrence 5 and Lawrence 4, but the inlet gas conditions differ significantly: 178 m^3/s (3,937,000 acfm) at 149°C (300°F) at Lawrence 5, compared with 190 m^3/s (403,000 acfm) at 138°C (280°F) at Lawrence 4.

Scrubber Modules--

The modules are significantly larger to accommodate the greater flue gas flow and temperature. The rectangular-throat, rod-deck scrubbers are 1.5 m (5 ft) by 11 m (37 ft), and the rods, which are constructed of 316L SS Schedule 80 pipe, have an outer diameter of 1.68 cm (6.63 in.). The flue gas entering the spray towers is contacted by a single level of slurry sprays operating in a countercurrent fashion approximately 3 m (10 ft) above the inlet duct. A single reaction tank equipped with four agitators and two strainers receives the spent slurry from both modules, as well as the fresh limestone slurry introduced into the system. After it has been retained for 10 minutes, the slurry is recycled to both the rod-deck scrubber and spray tower of both modules.

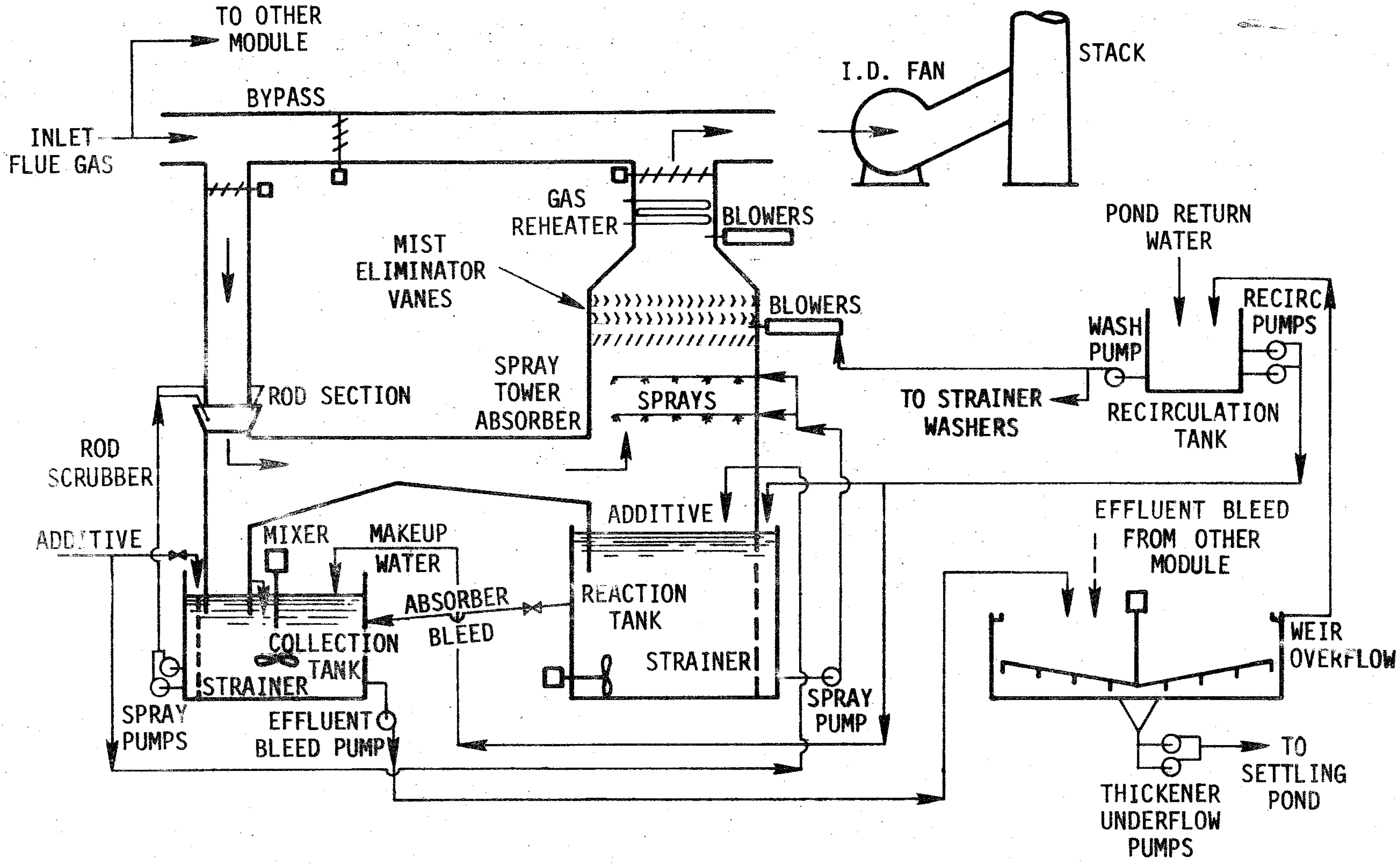

Figure 10. Simplified process flow diagram of one of the two Lawrence 4 scrubbing modules.

Waste Solids Disposal--

Although the two systems share the same sludge disposal ponds, Lawrence 5 is not equipped with a liquid staging and thickening system. Spent slurry (forcibly oxidized by air sparging) is bled from the system by effluent bleed pumps that discharge the reaction tank underflow directly to the ponds. Supernatant is returned to the process and added directly to the reaction tank, where a 10 percent solids level is maintained for liquid level control.

Figure 11 shows a simplified process flow diagram of the Lawrence 5 scrubbing system.

PROCESS DESIGN

Fuel

The Lawrence scrubbing systems were designed to process flue gas resulting from the combustion of pulverized-coal in the boilers. The coal is a low-sulfur, subbituminous grade, originating from mines located in Medicine Bow, Wyoming. Table 8 presents fuel specifications and consumption rates of the performance coal.

Inlet and Outlet Gas Conditions and Removal Efficiencies

The inlet and outlet gas conditions of the scrubbing systems and particulate and sulfur dioxide design removal efficiencies are summarized in Table 9. The values presented are based on the performance coal data summarized in Table 8.

Scrubber Modules

Each scrubbing system is equipped with two modules, each containing a rod-deck venturi scrubber in series with a spray tower absorber. Whereas Lawrence 4 is equipped with four slurry hold tanks, Lawrence 5 has only one. Lawrence 5 has less liquid staging for two major reasons: the existing reaction tank for the original furnace-injection system was available for use in the

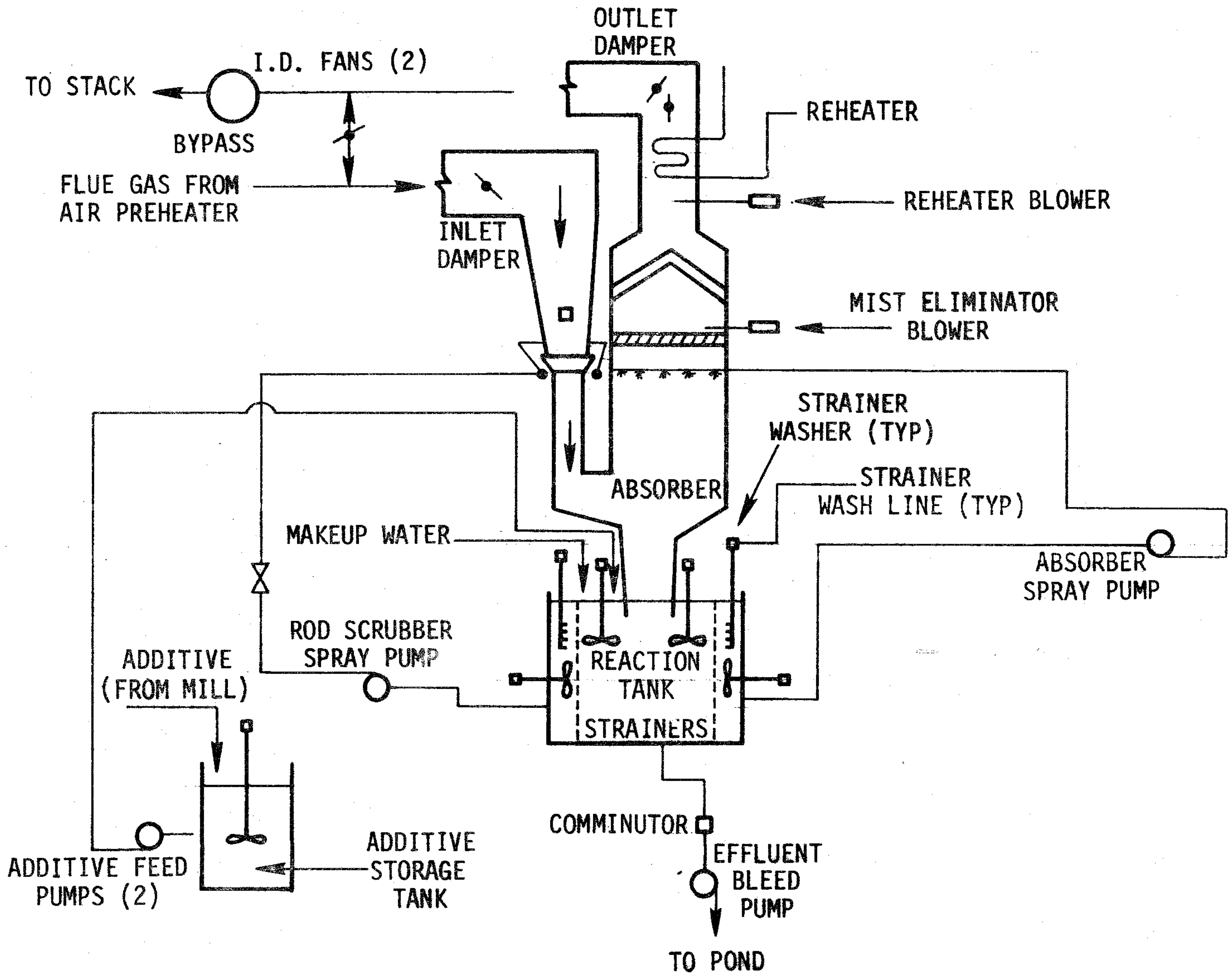

Figure 11. Simplified process flow diagram of one of the two Lawrence 5 scrubbing modules.

TABLE 8. SPECIFICATIONS AND CONSUMPTION RATES OF PERFORMANCE COAL[a]

Category	Lawrence 4	Lawrence 5
Maximum consumption, Mg/h (tons/h)	45 (50)	145 (160)
Heating value, kJ/kg (Btu/lb)	23,260 (10,000)	
Ash, percent	9.8	
Moisture, percent	11.8	
Carbon, percent	60.7	
Sulfur, percent	0.55	
Chlorine, percent	0.03	
Ash analysis		
Silicon dioxide, percent	38.0	
Aluminum oxide, percent	23.9	
Calcium oxide, percent	13.2	
Ferric oxide, percent	9.5	
Magnesium oxide, percent	3.5	

[a] Analyses are as-received average values.

TABLE 9. INLET AND OUTLET GAS CONDITIONS
AND DESIGN REMOVAL EFFICIENCIES

Category	Lawrence 4	Lawrence 5
Superheater outlet, Mg/h (lb/h)	382 (842,100)	1,272 (2,805,000)
Rod-deck scrubber inlet		
Volume, m^3/s (acfm)	190 (403,000)	600 (1,271,000)
Weight, Mg/h (lb/h)	585 (1,290,000)	1,713 (3,777,000)
Temperature, °C (°F)	138 (280)	149 (300)
Sulfur dioxide, ppm	748	748
Spray-tower absorber inlet		
Volume, m^3/s (acfm)	165 (349,000)	513 (1,088,000)
Weight, Mg/h (lb/h)	607 (1,338,000)	1,786 (3,937,000)
Temperature, °C (°F)	51 (124)	52 (126)
Scrubbing system outlet		
Volume, m^3/s (acfm)	171 (363,000)	551 (1,168,000)
Weight, Mg/h (lb/h)	607 (1,339,000)	1,788 (3,941,000)
Temperature, °C (°F)	62 (144)	69 (156)
Sulfur dioxide, ppm	200	359
Sulfur dioxide removal efficiency, percent	73	52
Particulate removal efficiency, percent	98.9	98.9

new tail-end system, thus providing a substantial savings in capital and time; and the percentage of sulfur dioxide removal is substantially less (52 versus 73 percent). Tables 10 and 11 summarize the design parameters and operating conditions of the Lawrence scrubbing modules and ancillary equipment.

Mist Eliminators

Each module is equipped with its own separate mist eliminator, which is situated in the spray tower horizontal to the gas stream. The mist eliminators (a proprietary two-stage design) are preceded by a precollector (bulk entrainment separator). They are constructed of a fiberglass reinforced plastic (FRP) capable of withstanding exposure to 205°C (400°F). Table 12 summarizes design parameters and operating conditions.

Reheaters

Each module is equipped with its own reheater, which is situated in the spray tower downstream of the mist eliminator. The reheaters elevate the discharge gas temperature to avoid downstream condensation and corrosion, suppress plume visibility, and enhance plume rise and dispersion of pollutants. Table 13 summarizes reheater design and operating conditions.

Draft Losses

Draft losses through both systems (the boilers, stacks, and ducts) are summarized in Table 14.

Waste Solids Treatment and Disposal

Waste disposal design parameters and operating conditions are summarized in Table 15. The Lawrence 4 system features a treatment system that forcibly oxidizes virtually all the sulfite into sulfate in the slurry hold tanks and a thickener which concentrates waste slurry to 30 to 35 percent solids prior to disposal in the sludge ponds. The Lawrence 5 system disposes the waste slurry directly to the pond.

TABLE 10. ROD-DECK SCRUBBER DESIGN PARAMETERS AND OPERATING CONDITIONS

Category	Lawrence 4	Lawrence 5
Number	2	2
Type	Rectangular, variable-throat, rod-deck venturi	Rectangular, variable-throat, rod-deck venturi
Flue gas volume, m^3/s acfm	95 (201,500)	300 (635,500)
Flue gas temperature, °C(°F)	138 (280)	149 (300)
Pressure drop, kPa (in. H_2O)	2.3 (9.0)	2.3 (9.0)
Liquid recirculation rate, liters/s (gpm)	227 (2,600)	656 (10,400)
Liquid-to-gas ratio (L/G), liters/m^3 (gal/10^3 acf)	2.4 (18)	2.2 (16)
Materials of construction		
Venturi approach	316L SS	316L SS
Throat	316L SS	316L SS
Rod-deck	Rubber-coated fiberglass (Norel) rods	316L SS
Slurry hold tanks		
Number	2	1[a]
Capacity, liters (gal)	189,600 (50,100)	2,300,000 (600,000)
Rentention time, min	14	10
Agitators, number	1	4
Materials of construction	Carbon steel	Carbon steel

[a] One slurry hold tank with a liquid capacity of approximately 2.3 million liters (600,000 gal) provides a retention time of 10 minutes for the spent slurry from both modules. Thus, half of the tank's capacity is provided for the rod-deck scrubbers and half for the spray tower absorbers.

TABLE 11. SPRAY TOWER ABSORBER DESIGN PARAMETERS AND OPERATING CONDITIONS

Category	Lawrence 4	Lawrence 5
Number	2	2
Type	Vertical, counter-current spray tower	Vertical, counter-current spray tower
Flue gas volume, m^3/s (acfm)	82.4 (174,500)	257 (544,000)
Flue gas temperature, °C (°F)	51 (124)	52 (126)
Pressure drop, kPa (in. H_2O)	0.6 (2.5)	0.2 (0.8)
Liquid recirculation rate, liters/s (gpm)	334 (5300)	656 (10,400)
L/G, liters/m^3 (gal/10^3 acf)	4.1 (30)	2.6 (19)
Materials of construction	316L SS	316L SS
Slurry hold tanks		
Number	2	1[a]
Capacity, liters (gal)	262,000 (69,200)	2,300,000 (600,000)
Retention time, min	10	10
Agitators, number	1	4
Materials of construction	Carbon steel	Carbon steel

[a] One slurry hold tank with a liquid capacity of approximately 2.3 million liters (600,000 gal) retains the spent slurry from both modules for 10 minutes. Thus, half the tank's capacity is provided for the rod-deck scrubbers and half for the spray tower absorbers.

TABLE 12. MIST ELIMINATOR DESIGN PARAMETERS AND OPERATING CONDITIONS

Total number	4
Number per module	1
Type	Chevron
Configuration (relative to gas flow)	Horizontal
Materials of construction	FRP
Number of stages	3[a]
Number of passes per stage	3[b]
Shape	A-frame

[a] A bulk entrainment separator is incorporated in the mist eliminator design to remove medium- to large-size droplets from the gas stream prior to passage through the chevron vanes. The bulk entrainment separator is, in essence, an additional mist eliminator stage.

[b] Three passes per chevron stage.

TABLE 13. REHEATER DESIGN PARAMETERS AND OPERATING CONDITIONS

Total number	4
Number per module	1
Type	Indirect, in-line
Heating medium	Hot water
Number of rows per exchanger	4
Configuration	Staggered, circumferential finned tubes
Tube size, outer diameter, cm (in.)	2.5 (1.0)
Materials of construction	Carbon steel
Heating medium source	Deaerator
Energy requirement, percent[a]	1.25

[a] Percent of boiler input.

TABLE 14. GAS-SIDE PRESSURE DROP DATA

Category	Lawrence 4	Lawrence 5
Boiler, air preheater, and duct work, kPa (in. H_2O)	2.8 (11.2)	4.3 (17.0)
Rod-deck scrubber, kPa (in. H_2O)	2.3 (9.0)	2.3 (9.0)
Spray tower and discharge duct work, kPa (in. H_2O)	0.6 (2.5)	0.2 (0.8)
Reheater, kPa (in. H_2O)	0.1 (0.5)	0.1 (0.5)
Discharge duct work and stack, kPa (in. H_2O)	0.2 (0.8)	0.3 (1.5)
Total, kPa (in. H_2O)	6.0 (24.0)	7.2 (28.8)

TABLE 15. WASTE DISPOSAL DESIGN PARAMETERS AND OPERATING CONDITIONS

Category	Lawrence 4	Lawrence 5
Waste stream characteristics		
Flow, kg/h (lb/h)	6,075 (13,392)	15,444 (34,048)
Solids, percent	30-35	10
Treatment method	Forced oxidation	
Disposal ponds		
Number	3	
Type	Onsite, unlined settling ponds	
Area, m^2 (acre)	16,000 (4); 65,000 (16); 113,000 (28)	
Transporation method	Pipeline	
Pond water return, liters/s (gpm)	8.2 (130)	16.8 (266)
Service life, yr	20	

Cleaning and Washing Devices

The Lawrence scrubbing systems are equipped with several mechanical and automatic cleaning devices designed to insure trouble-free, low maintenance operation. These devices are described briefly below:

- Each slurry hold tank has an in-tank strainer equipped with an automatic water wash. The strainer, which is a perforated plate containing 0.5 cm (3/16 in.) holes and constructed of carbon steel, prevents over-sized particles from entering the spray system and plugging the nozzles. After the automatic water wash backwashes the strainer to prevent solids accumulation, the collected particles are purged from the system as a bleed stream upstream of the strainer. Figure 12 provides a diagram of the strainer and wash mechanism.

- To prevent solids accumulation at the wet/dry interface each rod-scrubber inlet is equipped with a soot blower, which provides periodic compressed air at 1.4 MPa (200 psi).

- Each mist eliminator is equipped with a water washer that automatically provides intermittent (once per day), high-pressure [0.65 to 0.80 MPa (80 to 100 psig)] wash water. The water washer is located between the bulk entrainment separator and first chevron stage of each mist eliminator and provides an overspray and underspray to each of these stages.

- Two half-track soot blowers, located upstream of each reheater, provide 1.5 MPa (200 psig) of compressed air twice per shift for cleaning.

PROCESS CHEMISTRY: PRINCIPAL REACTIONS

The chemical reactions involved in the Lawrence wet-limestone scrubbing systems are highly complex. Although details are beyond the scope of this discussion, the principal chemical mechanisms are described in the following paragraphs.

The first and most important step in the wet-phase absorption of sulfur dioxide from the flue gas stream is diffusion

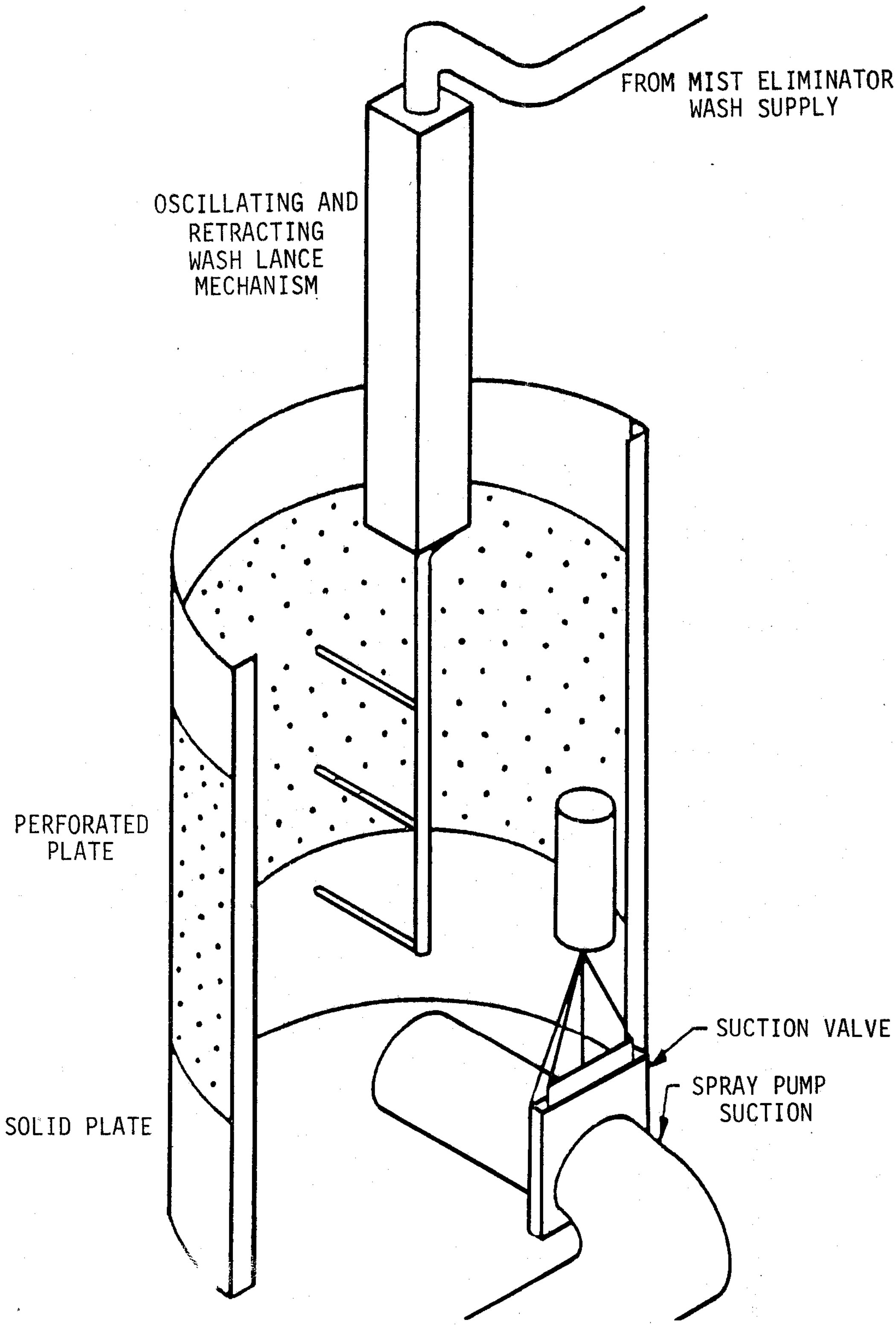

Figure 12. Diagram of slurry hold tank strainer and wash mechanism.

from the gas to the liquid phase. Sulfur dioxide is an acidic anhydride that reacts readily to form an acidic species in the presence of water.

$$SO_2\uparrow \rightleftharpoons SO_{2(aq.)}$$

$$SO_{2(aq.)} + H_2O \rightleftharpoons H_2SO_3$$

In addition, some sulfur trioxide is formed from further oxidation of the sulfur dioxide in the flue gas stream.

$$2SO_2\uparrow + O_2\uparrow \rightleftharpoons 2SO_3\uparrow$$

Because conditions are thermodynamically but not kinetically favorable, only small amounts of sulfur trioxide are formed. This species, like sulfur dioxide, is an acidic anhydride that reacts readily to form an acid in the presence of water.

$$SO_3\uparrow \rightleftharpoons SO_{3(aq.)}$$

$$SO_{3(aq.)} + H_2O \rightleftharpoons H_2SO_4$$

The sulfurous and sulfuric acid compounds are polyprotic species; the sulfurous species is weak and the sulfuric species, strong. Their dissociation into ionic species occurs as follows:

$$H_2SO_3 \rightleftharpoons H^+ + HSO_3^-$$

$$HSO_3^- \rightleftharpoons H^+ + SO_3^=$$

$$H_2SO_4 \rightleftharpoons H^+ + HSO_4^-$$

$$HSO_4^- \rightleftharpoons H^+ + SO_4^=$$

Analogous to the gas phase oxidation of sulfur dioxide to form sulfur trioxide, oxidation of the sulfite ion by dissolved oxygen (DO) in the scrubbing liquor occurs.

$$2SO_3^= + O_{2(aq.)} \rightleftharpoons 2SO_4^=$$

The limestone absorbent, which is approximately 93 percent calcium carbonate by weight, enters the scrubbing system as a slurry (10 percent solids) with water. It is insoluble in water, and solubility increases only slightly as the temperature increases. When introduced into the scrubbing system (Lawrence 4 collection tanks, Lawrence 5 reaction tank), the slurry dissolves and ionizes into an acidic aqueous medium, yielding the ionic products of calcium, carbonate, bicarbonate, and hydrogen.

$$CaCO_3 \downarrow \rightleftharpoons CaCO_{3(aq.)}$$

$$CaCO_{3(aq.)} \rightleftharpoons Ca^{++} + CO_3^{=}$$

$$Ca^{++} + H^{+} + CO_3^{=} \rightleftharpoons CaHCO_3^{+}$$

$$CaHCO_3^{+} \rightleftharpoons Ca^{++} + HCO_3^{-}$$

The chemical absorption of sulfur dioxide occurs in the venturi scrubber and spray tower and is completed in the external recirculation tank. In addition, the sulfite species accumulated in the slurry circuit is forcibly oxidized to sulfate in the recirculation tanks by bubbling air into the tanks at an air stoichiometry of 400 percent. The sulfate formed by forced oxidation plus the sulfate species already present in the slurry (formed by natural oxidate) precipitate as calcium salts, and the scrubbing solution is recycled. Following are the principal reaction mechanisms for product formation and precipitation.

$$SO_3^{=} + 1/2O_2 \rightleftharpoons SO_4^{=}$$

$$Ca^{++} + SO_4^{=} \rightleftharpoons CaSO_4$$

$$CaSO_4 + 2H_2O \rightleftharpoons CaSO_4 \cdot 2H_2O$$

The hydrated calcium sulfate reaction product, along with the collected fly ash and unreacted limestone, is transferred to the sludge ponds for final disposal. The supernatant is recycled to the system.

PROCESS CONTROL

The process control networks of the Lawrence limestone scrubbing systems rely on a significant amount of instrumentation to provide total automatic control of process chemistry. Included are sulfur dioxide gas analyzers (DuPont Photometric 460) for all gas inlet and outlet streams, magnetic flow meters (Foxboro) for all liquid slurry streams (recirculation, bleed, and feed lines), pH meters (Uniloc) for all the reaction tanks, and nuclear density meters for all the collection and reaction tanks. This instrumentation provides the basis of the control network that maintains particulate and sulfur dioxide removal efficiencies at desired levels while preventing the loss of chemical control and subsequent scale formation, corrosion damage, and/or plugging. The effect of the Lawrence control network on the performance of these major functions is briefly described in the following.

Particulate Removal

Particulate removal is maintained by controlling gas-side pressure drop across the rod-decks situated in the throat area of each module through regulation of the vertical spacing between the two rows of rods in response to gas flow. This maintains a set gas-side pressure drop of 2.25 kPa (9.0 in. H_2O) across the rods and insures particulate removal efficiency at 43 ng/J (0.1 lb/10^6 Btu) of heat input to the boiler.

Sulfur Dioxide Removal

Sulfur dioxide removal is maintained by regulating the flow of limestone to the scrubbing systems as a function of inlet sulfur. A characterized coal flow signal is used to indicate the inlet sulfur content of the flue gas, and this signal regulates the limestone feed rate. The coal flow signal will only be related to inlet sulfur conditions if the sulfur content of the coal is constant, and an operator selected stoichiometry bias allows correction of the limestone demand signal to account for change in the coal sulfur content. The sulfur in the coal is usually constant; therefore, the coal flow signal provides an accurate indication of the inlet sulfur conditions for all boiler loads. This allows the limestone feed rate to be accurately varied for the correct stoichiometry rate throughout the load range. This permits operation at design removal efficiencies while preventing the loss of chemical control, which can lead to formation of hard scale (gypsum), soft scale (calcium sulfite, calcium carbonate), and/or corrosion. Any of these phenomena can cause forced outages for cleanout or necessary repairs to damaged scrubber internals.

Spent Slurry Bleed

The spent slurry, consisting of collected fly ash, calcium sulfate, and unused reagent, accumulates in the slurry circuits, and must be discharged from the system in order to maintain system removal efficiency and process chemistry integrity.

In the Lawrence 4 scrubbing system, discharge occurs in the liquid staging system where the slurry from the reaction tanks (spray-tower-absorber slurry hold tanks--one per module) is bled to the collection tanks (rod-deck venturi scrubber slurry hold tanks--one per module). Spent slurry that accumulates in the slurry circuit of the rod-deck scrubber is discharged from the collection tanks by variable-drive, effluent bleed pumps. The solids in the reaction tanks are controlled at the 5 percent level by a constant gravity-flow bleed stream, which discharges to the collection tanks; those in the collection tanks are controlled at the 8 to 10 percent level by varying the effluent-bleed-pump flow. The effluent bleed stream is transferred to the thickener, where the slurry is concen trated to 30 to 35 percent solids before it is discharged to the sludge ponds. Solids content in the collection tanks and thickener is monitored via nuclear density meters placed in the spray lines.

Spent slurry is discharged from the Lawrence 5 scrubbing system in a manner similar to that described in the above for Lawrence 4. Notable differences are the lack of selective liquid staging and thickening in Lawrence 5, which is equipped with only one reaction tank for scrubbing modules, and the direct transfer of the effluent bleed stream to the sludge ponds without a preceding thickening step. The solids in the reaction tank are controlled at the 10 percent level by cycling the effluent bleed pump on and off.

Water Balance

Freshwater, thickener overflow water, and pond return water are used to compensate for water loss due to evaporation, mist carryover, water of hydration, and residual liquor trapped by the waste solids.

Procedures for maintaining water balance in the two systems differ because of the presence of additional liquid-staging and thickening equipment in Lawrence 4. For Lawrence 4, freshwater is used to slurry limestone prepared in the ball mill. Dilution water, which is added to the slurry to dilute the solids control of the mill effluent, originates from the recirculation tank, which receives pond return water and thickener overflow. This water is used to maintain liquid levels in the slurry hold tanks and also for mist eliminator wash and tank strainer wash.

The water balance network is essentially the same for Lawrence 5 except that, since Lawrence 5 contains no thickener, pond return water is not the only component of the dilution water. As in the other system, this water is used to maintain liquid level in the slurry hold tank and also for mist eliminator and tank strainer wash.

Scale Prevention

Sulfate scale* is a chemical phenomenon resulting from general or localized losses of chemical control in the scrubbing system. It plagues limestone systems because their pH operating range is generally in the slightly acidic to neutral range of 5 to 7. Calcium sulfate is generally formed in the system because of sulfite oxidation in the slurry circuit. Uncontrolled crystallization occurs when the system becomes excessively supersaturated with calcium sulfate, and hard scale forms on the system components such as walls, piping, nozzles, and other internals.

This problem is minimized in the slurry hold tanks of the Lawrence scrubbing systems by controlled desupersaturation, which is effected by providing calcium sulfate seed crystals for crystal growth sites, providing and maintaining adequate solids levels in the slurry circuits, and providing adequate mixing and retention time in the slurry hold tanks.

Precipitation of calcium sulfate is maintained by providing a sufficient amount of seed crystals as crystal growth sites in the slurry circuit and controlling saturation below the critical supersaturation level. Sufficient seed crystals are miantained by controlling the percent solids in the slurry circuits (5 percent solids in the Lawrence 4 reaction tanks; 10 percent solids in the Lawrence 4 collection tanks and the Lawrence 5 reaction tank). Each slurry hold tank is equipped with top-and-side entry agitators. In addition, the collection tanks provide a 14-minute retention time and the reaction tanks a 10-minute retention time.

The sulfates formed by oxidation are discharged from the systems by the effluent bleed pumps. The Lawrence 4 system is equipped with a thickener which concentrates the slurry before it is pumped to the pond on the opposite side of the site, thus reducing the amount of the solids from the thickener and eliminates the soluble sulfites recycled from the thickener overflow to the scrubbers. The effluent bleed from the Lawrence 5 scrubbers is pumped directly to the ponds that are in close proximity to the unit.

*Sulfate scale is actually calcium sulfate dihydrate, or gypsum, commonly referred to in the industry as hard scale to differentiate it from the scale formed by deposition of calcium sulfate hemihydrate commonly referred to as soft scale.

SECTION 4
FGD SYSTEM PERFORMANCE

BACKGROUND INFORMATION

The original limestone furnace-injection and tail-end scrubbing system retrofitted on Lawrence 4 were started up in November 1968 and operated until mid-September 1976, when it was shut down to perform a scheduled turbine overhaul, which took 2-1/2 months. During this time, construction and erection of the new rod-deck venturi scrubber and spray tower absorber system were completed. The new system went into service in early January 1977. During this November 1968 to September 1976 period, the original system accumulated approximately 27,000 hours of service on coal-fired flue gas.

The original limestone furnace-injection and tail-end scrubbing system (installed as new equipment) on Lawrence 5 was started up in November 1971 and operated until March 20, 1978, when it was shut down to tie the new scrubbing system into the flue gas path. The new rod-deck scrubber and spray tower absorber modules were erected directly behind the existing system, which remained in service during construction of the new system. Because the new system was designed to use the original reaction tank, spray pumps, induced-draft fans, and stack, a 4-week outage was required to complete installation. The new system went into service on April 14, 1978. During the November 1971 to March 30, 1978, period, the original system accumulated approximately 23,000 hours of service on coal-fired flue gas.

OPERATING HISTORY AND PERFORMANCE

Because the new Lawrence 4 scrubbing system was placed in the flue-gas path approximately 15 months earlier than the Lawrence 5 system, virtually all the operating information and data now available reflect the experience of Lawrence 4. Through the end of September 1978, this system had accumulated approximately 10,000 hours of service on coal-fired flue gas. It should be noted that the scrubbing system was bypassed from April 1, 1977, to September 15, 1977, because natural gas was available, which precluded the necessity of scrubber operations.

During the course of the initial and subsequent operation of Lawrence 4, a number of preliminary performance tests and a complete acceptance test were performed. Also, corrective measures were taken to solve a number of mechanical, chemical, and design-related problems that were encountered. The results of the acceptance tests, as well as information on problems and solutions, are provided in the following subsections.

PROBLEMS AND SOLUTIONS

Mechanical Problems

The in-tank strainer washers failed repeatedly during initial operation and required extensive overhauling. The failures, which subsequently necessitated overhaul, were attributed to mechanical malfunction of limit switches, improper operation, or operator error. Another contributing factor was an inoperable air compressor that failed to provide forced oxidation and agitation in the cavity behind the strainer, thus allowing the cavity to become plugged during shutdown periods. This problem was resolved by operating the air compressor.

Limestone slurry is transferred to the reaction tank of each module by positive-displacement screw-type pumps. The rubber liners and rotors of the pumps have been subject to premature failures, consistently wearing out within 10 to 15 weeks. No corrective action has been taken; rather, the liners and rotors are replaced prior to complete failure. This approach has been adopted for several reasons. The pumps accurately control the rate of limestone slurry flow to each reaction tank and thus are integral components in maintaining control of process chemistry. Because the rate of wear of the liners and rotors is predictable, they can be replaced before complete failure occurs, and finally, since the entire system has only two additive feed pumps, such periodic replacement is not costly.

Some minor agitator problems have been encountered. Several of the rubber-coated blades of the top-entry agitators in the collection tanks failed and were replaced by the manufacturer. Bearing failures in the side-entry agitators of the reaction tanks were attributed to improper lubrication.

A number of small cracks have been observed in the mist eliminators. Some cracking and failure of pumps and pipes have been encountered because of freezing and severe winter weather conditions, especially during the initial phases of operation when heat tracing and insulation were not completed.

Since the scrubbing system is located completely outdoors, the completion of heat tracing and insulation, plus the erection of enclosures around the spray pumps, resolved many of these problems. Some freezing and subsequent plugging, however, have recurred around the clarifier.

Chemical Problems

To date, no major episodes of scaling or corrosion have occurred in the system. Some minor problems that have had chemical ramifications concern the maintainance of adequate solids levels in the reaction tanks. Specifically, during initial operation, it was determined that water pressure to the mist eliminator washers was insufficient. Before this problem was corrected by installing a booster pump in the wash system, the frequency of washing had to be doubled to twice every 24 hours to compensate for low water pressure and to insure mist eliminator cleanliness. Because the spent wash water eventually flows into the reaction tank, doubling the amount of spent wash water made it difficult to maintain the 5 percent solids level. This dilution diminished the concentration of sulfate seed crystals and resulted in sporadic episodes of scaling within the spray towers. The scale buildup never exceeded 3 mm (1/8 in.) and was corrected with the insertion of the booster pump, which made more than one daily cleaning of the mist eliminator unnecessary.

Design-related Problems

The incoming flue gas comes into contact with slurry sprayed by nonatomizing fan-type nozzles located around the rectangular perimeter of the venturi scrubber just above the rod decks. Because of the abrasive nature of the 10 percent solids slurry sprayed through these nozzles, sacrificial wear plates were inserted directly below the nozzles to prevent premature failure of materials in the converging section of the venturis. It should be noted that these wear plates were inserted into the venturis after initial startup, during the period when natural gas was fired in the boiler. A materials failure did not occur here, but it did at another utility installation (Sherburne County, Northern States Power Co.), which utilizes a similar scrubber design. The experience Combustion Engineering gained there prompted the insertion of wear plates at Lawrence. Time limitations necessitated making these insertions after startup. Figure 13 shows the arrangement of the variable-throat venturi scrubber and rod-decks, including the spray nozzles and wear plates.

Each module is equipped with three dampers that allow bypass or isolation during periods of gas/oil firing, reduced boiler load, or maintanance. One module is equipped with a double-

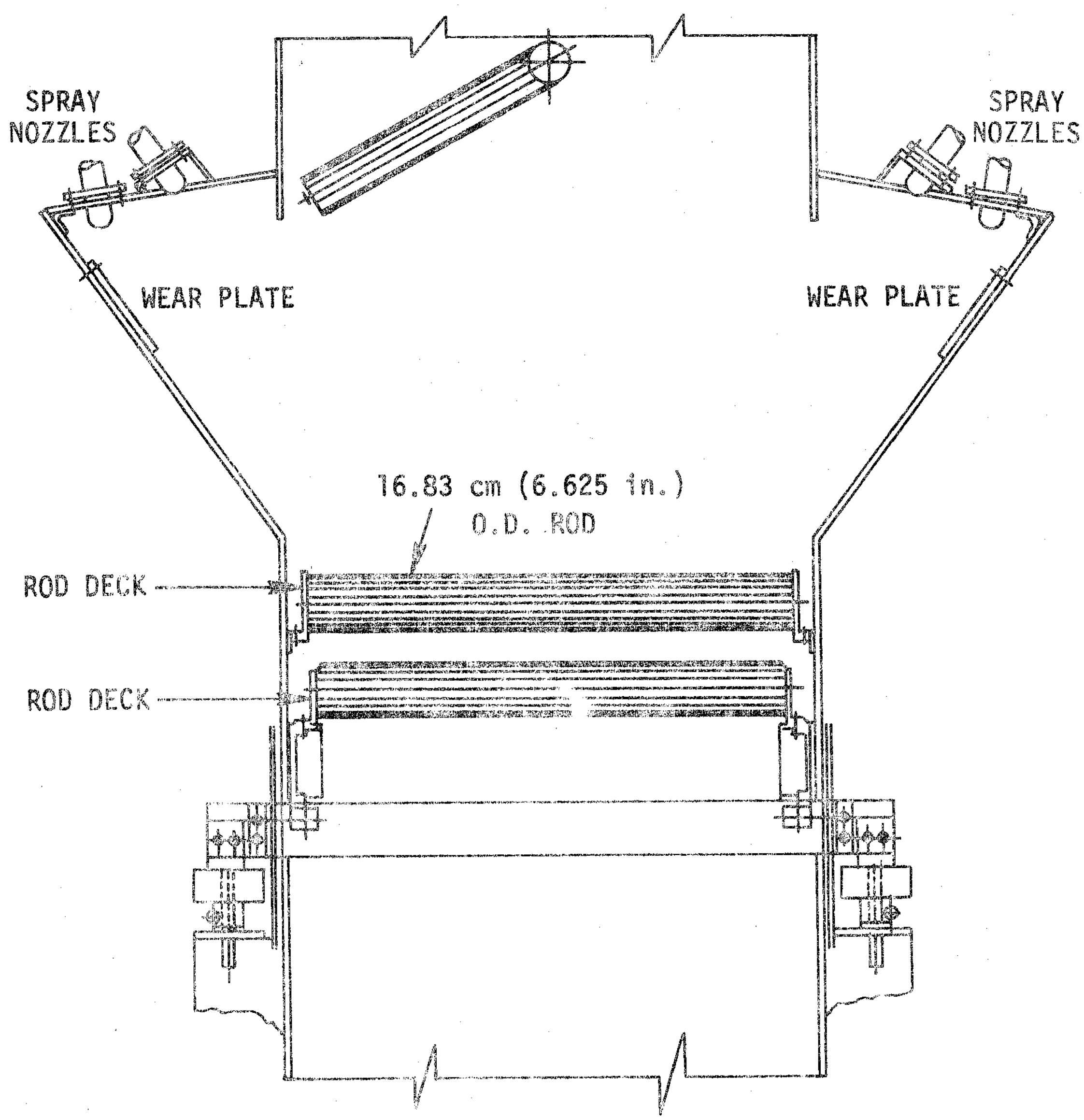

Figure 13. Arrangement of variable-throat rod-deck venturi scrubber.

louver bypass damper, whereas the other has a top-entry guillotine damper. A certain amount of gas leakage through these dampers was observed during a series of preliminary performance tests. This was corrected immediately by replacing the old seals. Combustion Engineering also determined that the damper drives were susceptible to frequent drifting that allowed the dampers to to move off their limit switches every 5 to 10 minutes, thus activating controls to drive them back to their original position. This caused flue gas to bypass the modules and activated nuisance alarms in the control room. The damper drives have been replaced with redesigned mechanisms by the damper supplier.

The soot blowers located at the inlets of the rod-deck venturi scrubbers were not adequately cleaning the wet/dry interfaces of solids buildup. The lances were subsequently modified to obtain better coverage, and have performed adequately since that time.

A materials failure detected in the FRP slurry spray piping was related directly to operation of a downstream butterfly control valve. The valve was throttling flow to the spray tower sprays, thus creating undue stress on the piping. Corrective action consisted of opening the valve completely during operation, thereby eliminating any turbulence and wear on the upstream piping.

Shortly after startup it was noticed that several spray pumps required repacking every 10 days. This problem was resolved by redesigning the seal water system so that the flow rate of the water was approximately doubled.

SYSTEM PERFORMANCE: DEPENDABILITY, REMOVAL EFFICIENCIES, AND CHEMICAL CHARACTERIZATION

As indicated previously, Lawrence 4 has accumulated approximately 10,000 hours of service time since commencing operations in January 1977, and the problems encountered have been minor in nature. Therefore system availability* during the January 1977 to September 1978 period was in the 90 to 95 percent range.†

A number of preliminary and acceptance performance tests of actual particulate and sulfur dioxide removal efficiencies were conducted by Combustion Engineering during the first year of operation. Measurements obtained included particulate removal, sulfur dioxide removal, and opacity, as well as chemical and physical measurements of the liquid and solids effluents from the system. The results of the acceptance performance tests are provided in Tables 16, 17, 18, and 19, and Figures 14 and 15.

The results of the performance tests, which have since been corroborated by subsequent operation, indicate the following: the system can achieve sulfur dioxide removal efficiencies as high as 96 to 98 percent when operating at optimum design conditions; it has demonstrated that a particulate removal capability in excess of 99 percent of the inlet particulate when the design pressure drop [2.25 kPa (9 in. H_2O)] is maintained across the rod-decks. This translates into an emission-outlet value of 34 ng/J (0.08 lb/10^6 Btu) heat input to the boiler when operating at optimum design conditions, and opacity measurements of between 2 and 8 percent have been achieved on the twin 2.5-m (8-ft) diameter stacks when operating at optimum design conditions.

*Availability index: the number of hours the system is available for operation (whether operated or not), divided by the number of hours in the period, expressed as a percentage.

†This range is a PEDCo Environmental estimate based on performance information provided by KP&L and Combustion Engineering. It should be noted that KP&L does not maintain separate records or operating logs for their scrubber plants. They are considered part of the power generating facility and as such are logged accordingly. This precludes the possibility of analyzing the dependability of the systems independently and presenting actual performance data other than estimates or ranges.

TABLE 16. SUMMARY OF LAWRENCE 4 SCRUBBING SYSTEM PERFORMANCE-- ANALYSIS OF SOLIDS: OCTOBER 1977

Category[a]	Test date					
	10/7	10/7	10/18	10/19	10/23	10/23
Mg, percent	0.1/<0.1	<0.1/<0.1	<0.1/<0.1	0.1/<0.1	<0.1/<0.1	0.1/ 0.1
Oxidation, percent	77.2/97.7	78.6/98.9	57.4/94.1	57.6/95.8	56.3/99.2	56.7/97.4
Utilization, percent	55.9/30.0	62.7/42.0	73.8/65.9	79.3/68.5	79.3/90.8	83.2/86.1
Solids, percent	7.0/7.9	8.5/7.8	12.4/9.0	11.7/8.4	12.8/5.2	12.0/9.8
$CaSO_3 \cdot 1/2H_2O$, percent	2.42/0.32	2.42/0.16	6.77/1.29	6.12/1.44	6.77/0.16	6.93/0.64
$CaSO_4 \cdot 2H_2O$, percent	10.93/18.63	11.82/19.89	12.18/27.23	11.11/29.56	11.64/27.95	12.18/32.4
$CaCO_3$, percent	6.46/25.21	5.21/16.09	4.37/8.75	2.91/8.33	3.12/1.66	2.5/2.12
Fly ash, percent	80.19/55.84	80.55/63.91	76.67/62.73	79.85/60.66	78.47/70.22	78.39/63.8

[a] Values reported for collection tank and reaction tank.

TABLE 17. SUMMARY OF LAWRENCE 4 SCRUBBING SYSTEM PERFORMANCE-- GYPSUM CRYSTALLIZATION DATA: OCTOBER 1977

Category[a]	Test date			
	10/7	10/18	10/23	10/23
Solids, percent	8.5/7.8	12.8/9.0	12.8/5.2	12.0/9.8
Gypsum, percent	1.00/1.55	1.51/2.45	1.49/1.45	1.46/3.18
Gypsum, relative saturation	1.41/1.18	1.34/1.10	1.30/1.12	1.33/1.18
Sulfur dioxide removal, percent	225/55	235/55	265/60	265/60
Oxidation, percent	78.6/98.9	57.4/94.1	56.3/99.2	56.8/97.4
Gypsum percipitation rate, millimoles/liter-minute	0.211/0.047	0.116/0.049	0.189/0.055	0.189/0.055
Forced oxidation	Yes/Yes	No/No	No/No	No/No

[a] Values reported for collection tank and reaction tank.

TABLE 18. SUMMARY OF OVERALL PERFORMANCE OF LAWRENCE 4 SCRUBBING: OCTOBER 1977

Category	Test blocks I	Test blocks II	Test blocks III
Inlet sulfur dioxide, ppm[a]		400-450	
Outlet sulfur dioxide, ppm[a]		10-20	
Sulfur dioxide removal, percent		95.5-97.5	
Limestone stoichiometry, percent	100	41	18
Limestone utilization, percent[b,c]	60/38	75/67	81/87
Sulfite oxidation, percent[c]	78/98	58/95	57/98
Solids, percent[c]	8.5/7.8	12.4/8.0	12.8/5.2
pH[c]	7.5/6.6	6.8/6.3	7.7/5.5
Ca^{++}, ppm[c]	876/715	801/702	781/669
Mg^{++}, ppm[c]	137/127	225/210	256/214
$SO_3=$, ppm[c]	106/23	100/87	89/214
$SO_4=$, ppm[c]	2340/2064	2570/2375	2598/2303
Gypsum relative saturation[c]	1.45/1.22	1.38/1.21	1.35/1.15
$CaSO_3 \cdot 1/2H_2O$, percent[d]	2.41/0.20	6.50/1.35	6.85/0.38
$CaSO_4 \cdot 2H_2O$, percent[d]	11.57/19.25	11.65/28.70	11.78/30.65
$CaCO_3$, percent[d]	5.85/21.52	3.74/8.59	2.83/2.35

[a] Corrected to 3 percent oxygen.

[b] Includes alkali contributed by limestone and fly ash.

[c] Values reported for collection tank and reaction tank.

[d] Weight percent.

TABLE 19. LAWRENCE 4 SCRUBBING SYSTEM PERFORMANCE SUMMARY: OCTOBER 1977

Date	10/18/77	10/10/77	10/12/77	10/12/77	10/14/77	10/18/77	10/18/77	10/19/77	10/20/77	10/24/77	10/24/77	10/24/77	10/25/77	10/25/77
Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Location	South outlet	South outlet	South outlet	South outlet	South outlet	South outlet	South outlet	South outlet	South outlet	South outlet	South outlet	South outlet	South inlet	South inlet
Particulate loading, mg/m^3 (gr/scf)	70.9 (0.031)	50.3 (0.022)	68.6 (0.030)	54.9 (0.024)	59.5 (0.026)	64.0 (0.028)	73.2 (0.031)	73.2 (0.032)	80.0 (0.035)	73.2 (0.032)	89.2 (0.039)	89.2 (0.039)	7037 (3.077)	6838 (2.990)
Particulate loading, mg/m^3 (gr/scf)	100.6 (0.044)	70.9 (0.031)	98.3 (0.043)	77.8 (0.034)	84.6 (0.037)	91.5 (0.040)	100.6 (0.044)	105.2 (0.046)	114.4 (0.050)	105.2 (0.046)	128.1 (0.056)	128.1 (0.056)	10,040 (4.39)	9765 (4.27)
Opacity, %	2.5	3.0	2.5	3.0	2.5	2.5	2.0	2.0	2.0	2.0	7.5	7.5		
Rod section pressure drop, kPa, (in. H_2O)	2.6 (10.4)	2.5 (10.1)	4.0 (16.0)	4.0 (16.0)	2.6 (10.4)	2.6 (10.4)	2.6 (10.4)	2.6 (10.4)	4.0 (16.0)	4.0 (16.0)	1.1 (4.5)	1.2 (4.6)	1.1 (4.5)	1.1 (4.5)
L/G,[a] liters/m^3 (gal/10^3 acf)	2.7/4.1 (20/30)	2.7/4.1 (20/30)	2.7/4.1 (20/30)	2.7/4.1 (20/30)	1.4/4.1 (10/30)	1.4/4.1 (10/30)	2.7/0 (20/0)	2.0/0 (15/0)	2.7/0 (20/0)	2.7/0 (20/0)	2.7/4.1 (20/30)	2.7/4.1 (20/30)	2.7/4.1 (20/30)	2.7/4.1 (20/30)
Excess air, %	64.7	67.6	63.3	63.3	61.5	64.8	60.2	60.2	61.9	63.9	68.4	68.4	68.4	68.4
Gas temperature, °C (°F)	63 (145)	62 (143)	61 (142)	62 (144)	63 (146)	63 (145)	62 (144)	62 (144)	62 (144)	62 (144)	64 (147)	64 (147)	142 (288)	144 (292)
Gas flow, m^3/s (ft^3/min)	108 (228,254)	108 (229,301)	111 (236,000)	109 (231,948)	113 (238,554)	108 (228,275)	106 (224,444)	108 (228,951)	109 (231,845)	111 (235,691)	65 (138,475)	65 (137,363)	72 (153,575)	74 (156,623)
Load, MW	51	52	52	52	53	51	51	51	51	51	51	51	52	52

[a] Rod-deck scrubber/spray tower absorber values.

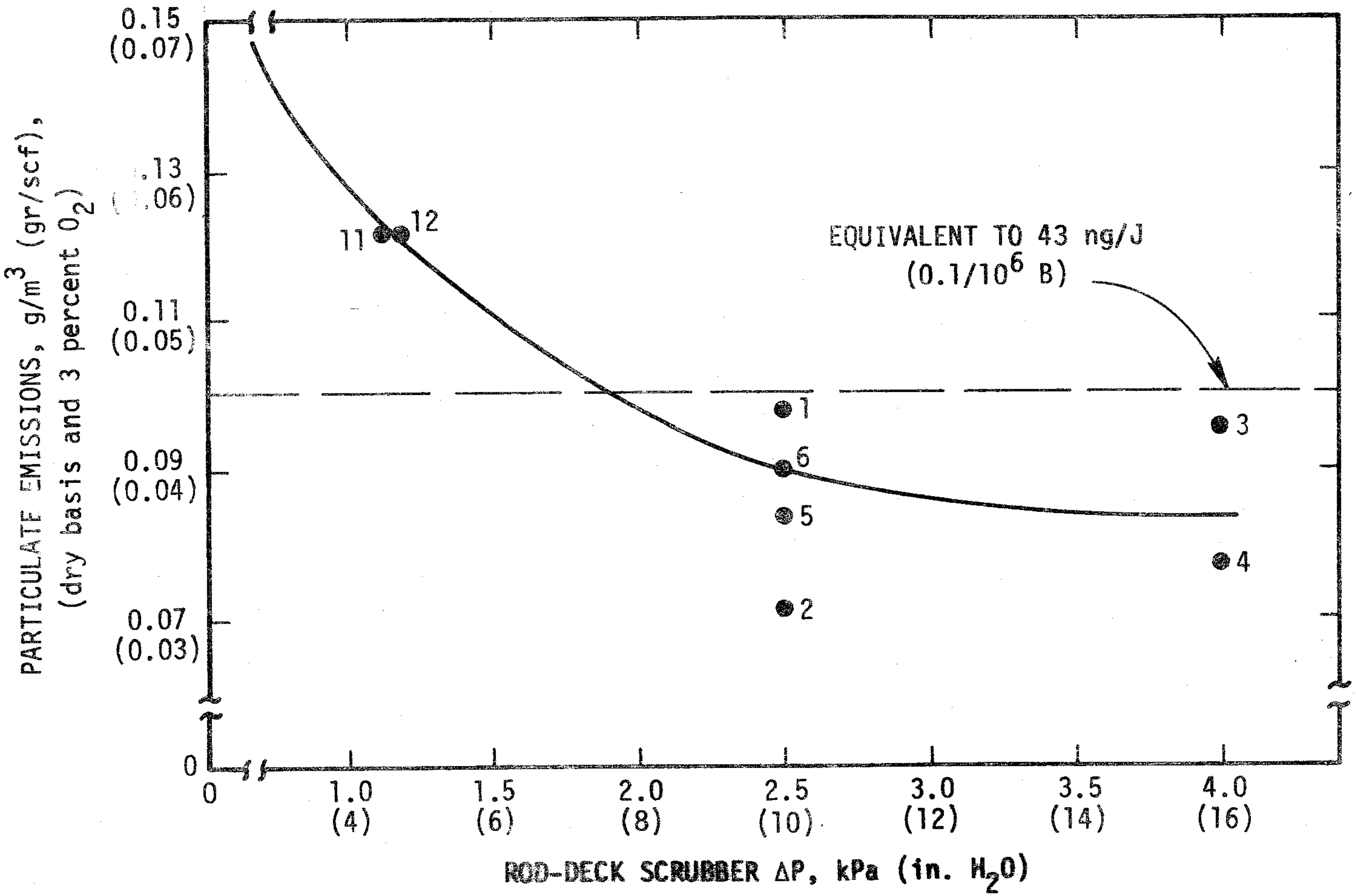

Figure 14. Lawrence 4 scrubbing system performance summary - particulate emission as a function of rod-deck venturi scrubber differential pressure: October 1977.

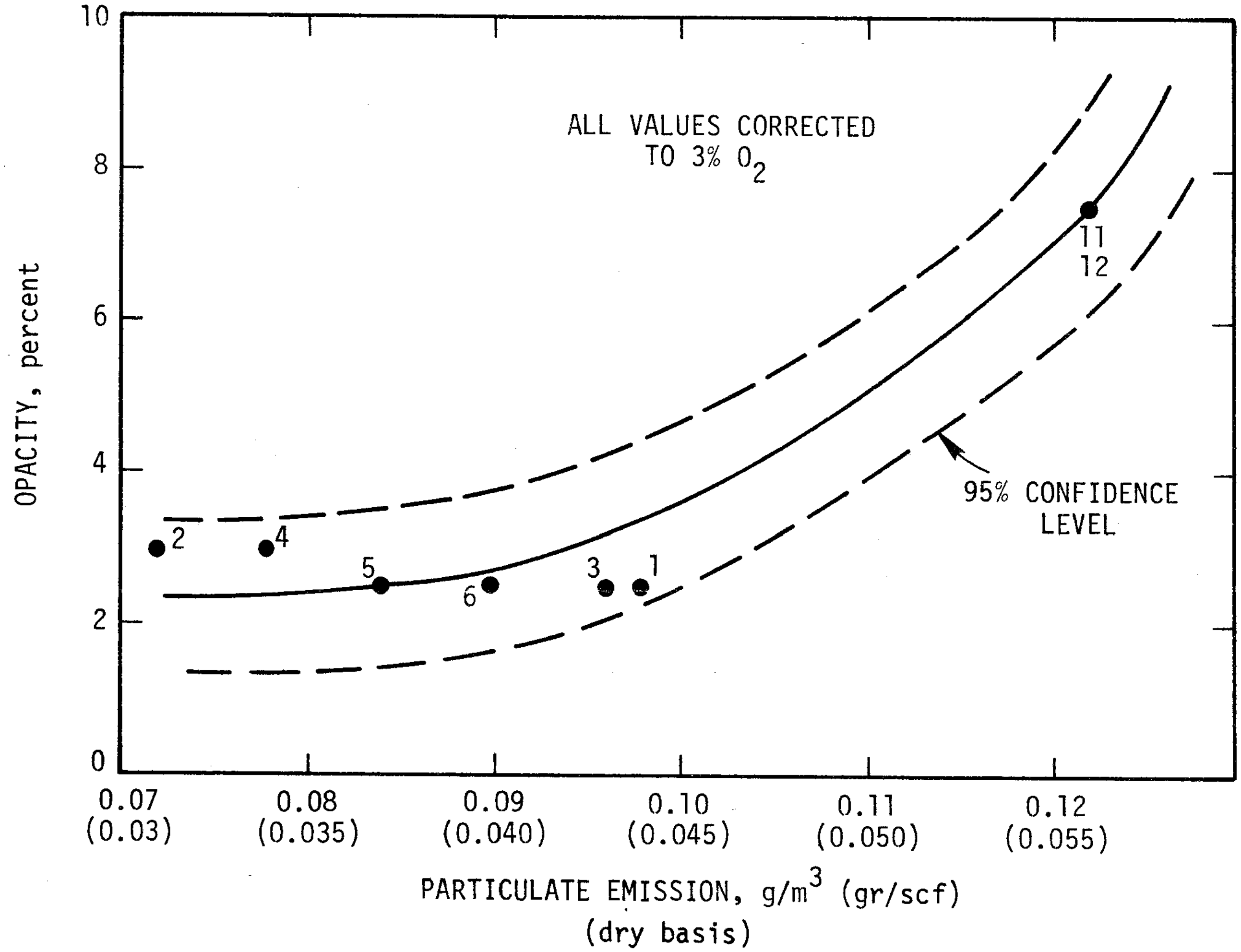

Figure 15. Summary of Lawrence 4 scrubbing system performance-particulate emission versus opacity: October 1977.

As indicated above, a number of chemical and physical process stream measurements were taken to determine reagent usage and material balance (see Tables 16, 17, and 18). An analysis of these results provides some interesting conclusions, the most notable of which is that the alkaline constituents (calcium oxide, magnesium oxide) in the collected fly ash provide the major portion of the alk li in the slurry circuit. This increases sulfur dioxide removal efficiencies during short-term performance tests and, more importantly, allows reduction in limestone feed rates during normal operations, thereby providing a substantial savings in annual costs for reagent consumption. One disadvantage is that the alkalinity contributed by the fly ash affects the degree of sulfite oxidation attained in the collection tanks. Without air addition, oxidation is generally in the 57 to 58 percent range; whereas air addition increases the oxidation to approximately 78 percent because the additional fly ash alkalinity increases slurry pH. Since sulfite solubility tends to decrease with increasing pH, less sulfite is available in solution for chemical conversion to sulfate. This could affect the quality of the sludge and gypsum relative saturation values.*

FUTURE OPERATIONS

Kansas Power and Light Company is now in the process of developing the Jeffrey Energy Center, a coal-fired power generating station with a capacity of 2880 MW (gross). This station is located in Pottawatomie County, Belvue, Kansas, and is composed of four 720-MW (gross) coal-fired units, which are scheduled for operation in October 1978, June 1980, 1982, and 1984. All of

*These effects may be overstated. Overall sulfite oxidation in the system without forced oxidation in the collection tanks is approximately 98 to 99 percent; with forced oxidation it is in excess of 99.5 percent (assuming air addition in the reaction tanks oxidizing 95 to 98 percent of the sulfite). These levels have had no pronounced effect on sludge quality or system chemistry.

these units will fire low-sulfur Gilette (Bell Ayr), a Wyoming coal supplied under long-term contract with the Amax Coal Company. The ultimate and ash analyses of this coal are provided in Table 20. The steam generators for Jeffrey 1 and 2 are supplied by Combustion Engineering, the turbine generators by Allis Chalmers.

In order to meet air emission regulations of the Department of Health and Environment of the State of Kansas and Federal New Source Performance Standards, Jeffrey 1 and 2 are equipped with emission control systems for the control of nitrogen oxides, particulate, and sulfur dioxide.

The emission control system for each unit is designed and supplied by Combustion Engineering and includes an overfire air system at the tangential-fired-pulverized burners for nitrogen oxide control, two electrostatic precipitators (ESP's) and crossover ducts upstream and downstream of the ESP's for particulate control, and six pressurized vertical spray towers for sulfur dioxide control.

The Jeffrey FGD systems consist of six vertical spray towers (one of which is a spare) for the removal of sulfur dioxide from 75 percent of the flue gas. The remaining 25 percent of the flue gas is bypassed around the spray towers to provide reheat* to the scrubbed gas prior to its discharge to the atmosphere through separate 183-m (600-ft) stacks. Four induced-draft fans (with respect to the boilers) are located upstream of the pressurized spray towers. The limestone used in the systems (for sulfur dioxide removal) is received at the plant as rock and ground by three wet ball mills with capacities of 11 Mg (12 tons)/h. One ball mill presently serves Jeffrey 1, one serves Jeffrey 2, and

* Only 75 percent of gas at Jeffrey is treated because of lower sulfur fuel, while Lawrence, having anticipated high sulfur coal origianlly, cleans 100 percent of gas flow. Consequently, in-line carbon steel reheaters were required for Lawrence.

TABLE 20. JEFFREY AVERAGE ULTIMATE AND ASH COAL ANALYSES

Ultimate analysis	
Heating value, kJ/kg (Btu/lb)	18,900 (8,125)
Ash, percent	5.8
Moisture, percent	30.0
Carbon, percent	48.5
Sulfur, percent	0.32
Chlorine, percent	0.01
Ash analysis	
Silicon oxide, percent	31.4
Ferric oxide, percent	4.1
Aluminum oxide, percent	16.2
Calcium oxide, percent	25.0
Magnesium oxide, percent	4.2

the other is a spare.* Each spray tower has two spray headers located 4 and 8 m (13 and 26 ft) above the gas inlet. Each system is equipped with four reaction tanks. Two of these tanks are shared by two spray towers each and two serve only one spray tower each. Each tower is also equipped with louver isolation and bypass dampers that permit module isolation from the gas path during periods of inactivity (reduced load, spare duty, or maintenance). A mixing chamber in each system permits drying of the scrubbed gas stream and mixing with the bypass gas stream prior to discharge to the atmosphere. The mist eliminators are identical to those at Lawrence (A-frame, two-stage with bulk-entrainment separator, FRP construction), as are the modules, which are constructed of 316 low-carbon stainless steel. Spent slurry collected in the reaction tanks is bled as a 10 percent solids slurry to a common transfer tank and then pumped to a settling pond located approximately 1.6 km (1 mi) from the plant. Water returned from the pond is used as makeup in the reaction tanks.

Figure 16 illustrates the arrangement of the steam generators and emission control systems for Jeffrey. Tables 21, 22, 23, and 24 summarize design information and criteria for Jeffrey 1 and 2.

---

* The ball mills will serve all four planned units at the Jeffrey site with one spare.

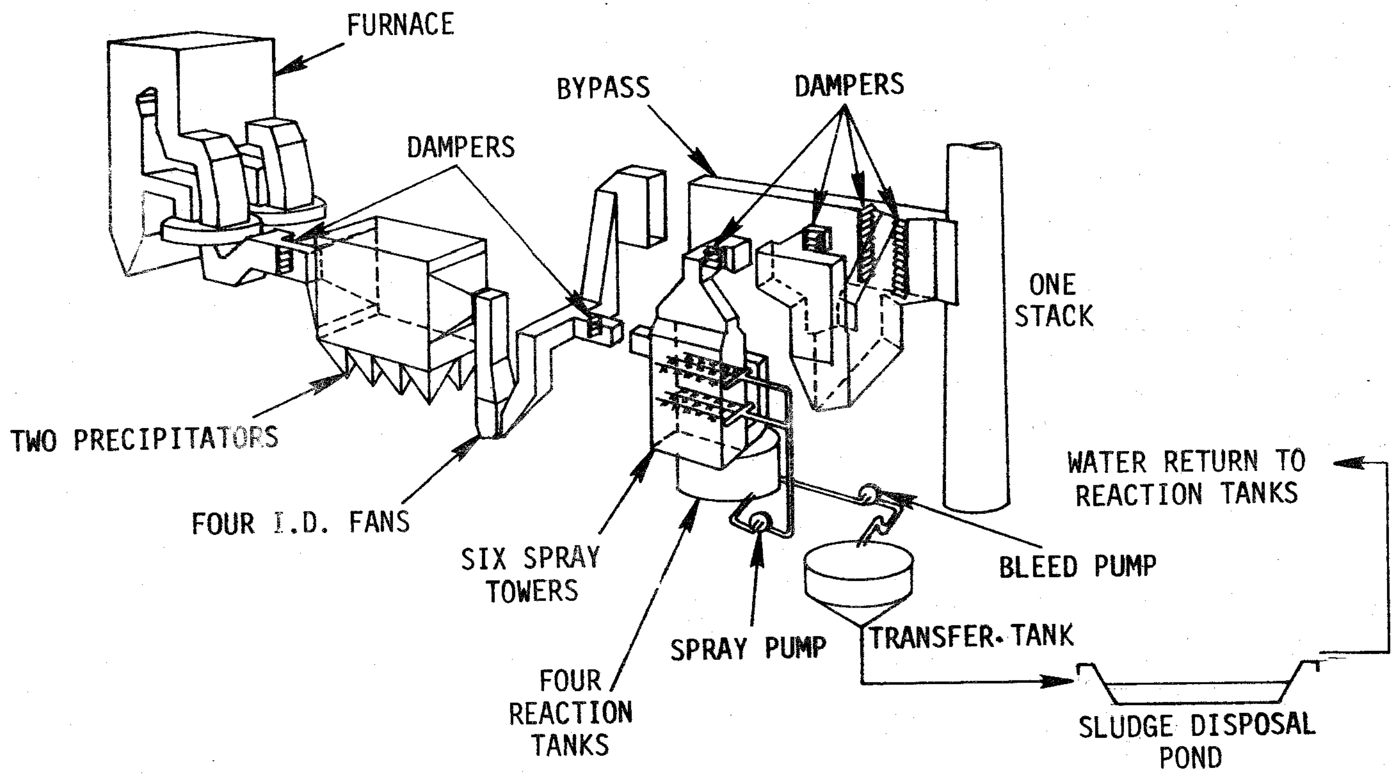

Figure 16. Schematic of Jeffrey steam generator and emission control equipment.

TABLE 21. SUMMARY OF JEFFREY 1 AND 2 EMISSION CONTROL SYSTEMS

	Jeffrey 1	Jeffrey 2
Unit capacity, MW (gross)	720	
Design coal, source	Gilette (Bell Ayr)	
Steam generator supplier	Combustion Engineering	
Turbine generator supplier	Allis Chalmer	
Particulate emission rate, ng/J (lb/10^6 Btu)	43 (0.1)	
Sulfur dioxide emission rate, ng/J (lb/10^6 Btu)	129 (0.3)	
Emission controls		
Particulate	ESP's	
Sulfur dioxide	Spray tower absorbers	
ESP supplier	CE-Walther	
ESP type	Cold side	
Number of ESP's	2	
FGD supplier	Combustion Engineering	
FGD design	Vertical spray tower	
Number of modules	6[a]	
Gas reheat, type	Bypass	
Gas bypass capability	Yes	
Sludge disposal	Unstabilized/onsite pond	
Startup date	10/78	6/80

[a] Five operational, 1 spare at full load.

TABLE 22. SUMMARY OF JEFFREY 1 AND 2 GAS FLOW RATES

Superheater outlet, Mg/h (10^3 lb/h)	2,290 (5,050)
ESP inlet, Mg/h (10^3 lb/h)	3,788 (8,351)
m^3/s (acfm)	1,312 (2,781,000)
°C (°F)	135 (276)
FGD inlet, Mg/h (10^3 lb/h)	2,651 (5,845)
m^3/s (acfm)	857 (1,815,000)
°C (°F)	135 (276)
FGD bypass, Mg/h (10^3 lb/h)	1,136 (2,505)
m^3/s (acfm)	334 (708,000)
°C (°F)	135 (276)
Stack inlet, Mg/h (10^3 lb/h)	3,876 (8,545)
m^3/s (acfm)	1,119 (2,370,000)
°C (°F)	77 (170)

TABLE 23. SUMMARY OF JEFFREY 1 AND 2 DRAFT LOSSES

Steam generator, air preheater, duct, kPa (in. H_2O)	5.16 (20.63)
ESP, kPa (in. H_2O)	0.28 (1.14)
Spray tower, duct, kPa (in. H_2O)	1.01 (4.04)
Reheat mixing chamber, kPa (in. H_2O)	0.75 (2.99)
Discharge duct and stack, kPa (in. H_2O)	0.65 (2.61)
Total, kPa (in. H_2O)	7.85 (31.41)

TABLE 24. SUMMARY OF JEFFREY 1 AND 2 LIQUID FLOW RATES

Limestone feed, kg/h (lb/h)[a]	5500 (12,130)
Tower recirculation rate, liters/s (gpm)[b,c]	908 (14,400)
Effluent bleed, Mg/h (lb/h)[c]	8.6 (19,000)
Makeup water, liters/s (gpm)	35 (557)

[a] Dry feed rate.
[b] Per module.
[c] Ten percent solids.

APPENDIX A

PLANT SURVEY FORM

A. Company and Plant Information

1. Company name: Kansas Power and Light Company

2. Main office: Topeka, Kansas

3. Plant name: Lawrence, Unit 4

4. Plant location: Lawrence, Douglas County, Kansas

5. Responsible officer: Derek Miller

6. Plant manager: Ron Teeter

7. Plant contact: Kelly Green

8. Position: Electric Production Manager

9. Telephone number: ________

10. Date information gathered: June 8, 1977

Participants in meeting	Affiliation
Ron Teeter	Kansas Power and Light
Bernard Laseke	PEDCo Environmental, Inc.
John Tuttle	PEDCo Environmental, Inc.
Jay Master	PEDCo Environmental, Inc.

B. Plant and Site Data

1. UTM coordinates: ______________________

2. Sea Level elevation: ______________________

3. Plant site plot plan (Yes, No): No
(include drawing or aerial overviews)

4. FGD system plan (Yes, No): Yes

5. General description of plant environs: Located in a lightly industrialized area on the outskirts of Lawrence

6. Coal shipment mode(s): rail

C. FGD Vendor/Designer Background

1. Process: Limestone slurry

2. Developer/licensor: Combustion Engineering

3. Address: 1000 Prospect Hill Road, Windsor, Connecticut 06095

4. Company offering process:

Company: Combustion Engineering

Address: 1000 Prospect Hill Road

Location: Windsor, Connecticut 06095

Company contact: A.J. Snider

Position: Manager, Environmental Control

Telephone number: (203) 688-1911

5. Architectural/engineer:

Company: ______

Address: ______

Location: ______

Company contact: ______

Position: ______

Telephone number: ______

D. Boiler Data

1. Boiler: Lawrence 4

2. Boiler manufacturer: Combustion Engineering

3. Boiler service (base, intermediate, cycling, peak):

Cyclic load

4. Year placed in service: 1959

5. Total hours operation (date): ______

6. Remaining life of unit: ______

7. Boiler type: Pulverized coal, (multiple-fuel design) balanced-draft, tangential-fired

8. Served by stack No.: ______

9. Stack height: 36 m (120 ft)

10. Stack top inner diameter: 2.5 m (8 ft)

11. Unit ratings (MW):

Gross unit rating: 125

Net unit rating without FGD: ______

Net unit rating with FGD: 115

Name plate rating:

12. Unit heat rate:

Heat rate without FGD:

Heat rate with FGD: 10,900 kJ/kWh (10,300 Btu/kWh)

13. Boiler capacity factor, (1977): 55 to 60

14. Fuel type: Coal

15. Flue gas flow rate:

Maximum: 190 m^3/s (403,000 acfm)

Temperature: 138°C (280°F)

16. Total excess air:

17. Boiler efficiency:

E. Coal Data

1. Coal supplier(s):

Name(s):

Location(s):

Mine location(s): Medicine Bow

County, State: Wyoming

Seam:

2. Gross heating value: 23,260 kJ/kg (10,000 Btu/lb)

3. Ash (dry basis): 9.8 (as received)

4. Moisture: 11.8

5. Sulfur (dry basis): 0.55 (as received)

6. Chloride: 0.03

7. Ash composition (See Table A1)

Table A1

Constituent	Percent weight
Silica, SiO_2	38.0
Alumina, Al_2O_3	23.9
Titania, TiO_2	
Ferric oxide, Fe_2O_3	9.5
Calcium oxide, CaO	13.2
Magnesium oxide, MgO	3.5
Sodium oxide, Na_2O	
Potassium oxide, K_2O	
Phosphorous pentoxide, P_2O_5	
Sulfur trioxide, SO_3	
Other	
Undetermined	

F. Atmospheric Emission Regulations

1. Applicable particulate emission regulation

   a) Current requirement: 43 ng/J (0.1 lb/10^6 Btu)

      Regulation and section: ______

   b) Future requirement: ______

      Regulation and section: ______

2. Applicable SO_2 emission regulation

   a) Current requirement: 129 ng/J (0.3 lb/10^6 Btu)

      Regulation and section No.: ______

   b) Future requirement: ______

      Regulation and section: ______

G. Chemical Additives: (Includes all reagent additives - absorbents, precipitants, flocculants, coagulants, pH adjusters, fixatives, catalysts, etc.)

1. Trade name: Limestone

   Principal ingredient: Calcium carbonate (93%), silicas (6%), Magnesium carbonate (1%)

   Function: Absorbent

   Source/manufacturer: N.R. Hamm Company

   Quantity employed: ______

   Point of addition: Reaction tank

2. Trade name: ______

   Principal ingredient: ______

   Function: ______

   Source/manufacturer: ______

   Quantity employed: ______

   Point of addition: ______

3. Trade name: ______

   Principal ingredient: ______

   Function: ______

   Source/manufacturer: ______

   Quantity employed: ______

   Point of addition: ______

4. Trade name: ______

   Principal ingredient: ______

   Function: ______

   Source/manufacturer: ______

   Quantity employed: ______

   Point of addition: ______

5. Trade name: ______

Principal ingredient: ______

Function: ______

Source/manufacturer: ______

Quantity employed: ______

Point of addition: ______

H. <u>Equipment Specifications</u>

1. Electrostatic precipitator(s) Not applicable

Number: ______

Manufacturer: ______

Design removal efficiency: ______

Outlet temperature: ______

Pressure drop: ______

2. Mechanical collector(s) Not applicable

Number: ______

Type: ______

Size: ______

Manufacturer: ______

Design removal efficiency: ______

Pressure drop: ______

3. Particulate scrubber(s) In conjunction with SO_2 absorber

Number: 2

Type: Rectangular variable-throat, rod-deck venturi

Manufacturer: Combustion Engineering

Dimensions: 0.9 m x 7 m (3 ft x 23 ft)

Material, shell: 316L SS

Material, shell lining: None

Material, internals: Rubber-coated fiberglass (Norel) rods

No. of modules per train: 1

No. of stages per module: 1

No. of nozzles or sprays:

Nozzle type: Nonatomizing, fan-type spray

Nozzle size:

Boiler load capacity: 50% each train

Gas flow and temperature: 95 m^3/s (201,500 acfm) at 138 °C (28 °F) each

Liquid recirculation rate: 227 liters/s (3600 gal/min) each

Modulation:

L/G ratio: 2.4 liters/s m^3 (18 gal/10^3 acf)

Pressure drop: 2.3 kPa (9.0 in. H_2O)

Modulation:

Superficial gas velocity:

Particulate removal efficiency (design/actual):

Inlet loading:

Outlet loading:

SO_2 removal efficiency (design/actual):

Inlet concentration: 748 ppm

Outlet concentration:

4. SO_2 absorber(s)

Number: 2

Type: Vertical, countercurrent spray tower

Manufacturer: Combustion Engineering

Dimensions:

Material, shell: 316L SS

Material, shell lining: None

Material, internals: FRP (spray headers)

No. of modules per train: 1

No. of stages per module: 2 spray levels

Packing/tray type: None

Packing/tray dimensions: Not applicable

No. of nozzles or sprays: 24 per level

Nozzle type: Spinner vane

Nozzle size: 220 gpm

Boiler load capacity: 50% each train

Gas flow and temperature: 82.4 m^3/s (174,500 acfm) at 51 °C (124 °F) each train

Liquid recirculation rate: 334 liters/s (5300 gpm)

Modulation: ______

L/G ratio: 4.1 liters/m^3 (30 gal/acf)

Pressure drop: 0.6 kPa (2.5 in. H_2O)

Modulation: ______

Superficial gas velocity: ______

Particulate removal efficiency (design/actual): 98.9 (venturi and spray tower combined)

Inlet loading: ______

Outlet loading: ______

SO_2 removal efficiency (design/actual): 73 (venturi and spray tower combined)

Inlet concentration: See particulate scrubber

Outlet concentration: 200 ppm

5. Wash water tray(s) Not applicable

Number: ______

Type: __________

Materials of construction: __________

Liquid recirculation rate: __________

Source of water: __________

6. Mist eliminator(s)

Number: Two, one per scrubbing train

Type: Chevron

Materials of construction: FRP

Manufacturer: __________

Configuration (horizontal/vertical): Horizontal

Number of stages: Two plus one bulk entrainment separator

Number of passes per stage: Three (chevron stage)

Mist eliminator depth: __________

Vane spacing: __________

Vane angles: __________

Type and location of wash system: Intermittent, high-pressure water wash directed to top of bulk entrainment separator and bottom of chevrons.

Superficial gas velocity: __________

Freeboard distance: __________

Pressure drop: __________

Comments: __________

7. Reheater(s): __________

Type (check appropriate category): __________

- [x] in-line
- [ ] indirect hot air
- [ ] direct combustion
- [ ] bypass
- [ ] exit gas recirculation
- [ ] waste heat recovery
- [ ] other

Gas conditions for reheat:

Flow rate: 171 m^3/s (363,000 acfm)

Temperature: 62°C (144°F)

SO_2 concentration: 200 ppm

Heating medium: Hot water

Combustion fuel: Not applicable

Percent of gas bypassed for reheat: Not applicable

Temperature boost (ΔT): 11°C (20°F)

Energy required: 1.25% of boiler output

Comments: Staggered, circumferential-finned tubes constructed of carbon steel

8. Fan(s)

Number: 2

Type: Induced draft

Materials of construction: Carbon steel

Manufacturer:

Location: Downstream of reheater

Rating:

Pressure drop:

9. Recirculation tank(s):

Number: 4, two per train (collection tank and reaction tank)

Materials of construction: Carbon steel

Function: Slurry retention, bleed, and limestone addition

Configuration/dimensions: Circular

Capacity: 262,000 liters (69,200 gal) (reaction tank)
190,000 liters (50,100 gal) (collection tank)

Retention time: 10 min (absorber); 14 min (venturi)

Covered (yes/no): No

Agitator: One per tank

10. Recirculation/slurry pump(s):

Number: 2 (1 spare)

Type: ______

Manufacturer: ______

Materials of construction: ______

Head: ______

Capacity: ______

11. Thickener(s)/clarifier(s)

Number: 1

Type: Denver

Manufacturer: ______

Materials of construction: Carbon steel

Configuration: ______

Diameter: 50 ft.

Depth: 10 ft.

Rake speed: ______

Retention time: ______

12. Vacuum filter(s) Not applicable

Number: ____________________

Type: ____________________

Manufacturer: ____________________

Materials of construction: ____________________

Belt cloth material: ____________________

Design capacity: ____________________

Filter area: ____________________

13. Centrifuge(s) Not applicable

Number: ____________________

Type: ____________________

Manufacturer: ____________________

Materials of construction: ____________________

Size/dimensions: ____________________

Capacity: ____________________

14. Interim sludge pond(s)

Number: 1

Description: Unlined pond

Area: 65,000 m^2 (16 acres)

Depth: ____________________

Liner type: ____________________

Location: Onsite

Service Life: 20 yr

Typical operating schedule: ____________________

____

Ground water/surface water monitors: ____________________

____

15. Final disposal site(s)

Number: Two

Description: Unlined settling ponds

Area: 16,000 m^2 (4 acres) and 113,000 m^2 (28 acres)

Depth:

Location: Onsite

Transportation mode: Pipeline

Service life: 20 yr

Typical operating schedule: Continuous

16. Raw materials production

Number: One for Units 4 and 5

Type: Wet ball mills

Manufacturer: KVS

Capacity: 12,000 lbs/h

Product characteristics: 80% <200 mesh particle size

I. Equipment Operation, Maintenance, and Overhaul Schedule

1. Scrubber(s)

Design life:

Elapsed operation time:

Cleanout method:

Cleanout frequency:

Cleanout duration:

Other preventive maintenance procedures: Soot blower to prevent solids accumulation at wet/dry interface

2. Absorber(s)

Design life: ____________________

Elapsed operation time: ____________________

Cleanout method: ____________________

Cleanout frequency: Maintenance performed as needed

Cleanout duration: ____________________

Other preventive maintenance procedures: ____________________

____

3. Reheater(s)

Design life: ____________________

Elapsed operation time: ____________________

Cleanout method: ____________________

Cleanout frequency: ____________________

Cleanout duration: ____________________

Other preventive maintenance procedures: Soot blowers upstream of each reheater

4. Fan(s)

Design life: ____________________

Elapsed operation time: ____________________

Cleanout method: ____________________

Cleanout frequency: Maintenance performed as needed

Cleanout duration: ____________________

Other preventive maintenance procedures: ____________________

____

5. Mist eliminator(s)

Design life: ____________________

Elapsed operation time: ____________________

Cleanout method: Wash water sprays

Cleanout frequency: Continuous/intermittent

Cleanout duration: Intermittent spray once per day

Other preventive maintenance procedures: ____________

____

6. Pump(s)

Design life: ____________

Elapsed operation time: ____________

Cleanout method: ____________

Cleanout frequency: ____________

Cleanout duration: ____________

Other preventive maintenance procedures: ____________

____

7. Vacuum filter(s)/centrifuge(s) Not applicable

Design life: ____________

Elapsed operation time: ____________

Cleanout method: ____________

Cleanout frequency: ____________

Cleanout duration: ____________

Other preventive maintenance procedures: ____________

____

8. Sludge disposal pond(s)

Design life: ____________

Elapsed operation time: ____________

Capacity consumed: ____________

Remaining capacity: ____________

Cleanout procedures: ______________________________

____

J. Instrumentation See text of report

A brief description of the control mechanism or method of measurement for each of the following process parameters:

- Reagent addition: ______________________________

  ____

- Liquor solids content: ______________________________

  ____

- Liquor dissolved solids content: ______________________________

  ____

- Liquor ion concentrations

  Chloride: ______________________________

  ____

  Calcium: ______________________________

  ____

  Magnesium: ______________________________

  ____

  Sodium: ______________________________

  ____

  Sulfite: ______________________________

  ____

  Sulfate: ______________________________

  ____

  Carbonate: ______________________________

  ____

  Other (specify): ______________________________

  ____

- Liquor alkalinity: ______________________________

  ____

- Liquor pH: ______________________________

  ____

- Liquor flow: ______________________________

  ____

- Pollutant (SO_2, particulate, NO_x) concentration in flue gas: ______________________________

  ____

- Gas flow: ______________________________

  ____

- Waste water ______________________________

  ____

- Waste solids: ______________________________

  ____

Provide a diagram or drawing of the scrubber/absorber train that illustrates the function and location of the components of the scrubber/absorber control system.

Remarks: ______________________________

____

____

____

____

K. Discussion of Major Problem Areas:

1. Corrosion: See the main body of the report concerning problem areas

   ____

2. **Erosion:** See the main body of the report concerning problem areas

3. **Scaling:** See the main body of the report concerning problem areas

4. **Plugging:** See the main body of the report concerning problem areas

5. **Design problems:** See the main body of the report concerning problem areas

6. **Waste water/solids disposal:** See the main body of the report concerning problem areas

7. Mechanical problems: See the main body of the report concerning problem areas

L. General comments:

APPENDIX B

PLANT SURVEY FORM

A. Company and Plant Information

1. Company name: Kansas Power and Light Company
2. Main office: Topeka, Kansas
3. Plant name: Lawrence, Unit 5
4. Plant location: Lawrence, Douglas County, Kansas
5. Responsible officer: Derek Miller
6. Plant manager: Ron Teeter
7. Plant contact: Kelly Green
8. Position: Electric Production Manager
9. Telephone number:
10. Date information gathered: June 8, 1977

Participants in meeting	Affiliation
Ron Teeter	Kansas Power and Light
Bernard Laseke	PEDCo Environmental, Inc.
John Tuttle	PEDCo Environmental, Inc.
Jay Master	PEDCo Environmental, Inc.

B. Plant and Site Data

1. UTM coordinates: ______

2. Sea Level elevation: ______

3. Plant site plot plan (Yes, No): No
(include drawing or aerial overviews)

4. FGD system plan (Yes, No): Yes

5. General description of plant environs: Located in a lightly industrialized area on the outskirts of Lawrence

6. Coal shipment mode(s): rail

C. FGD Vendor/Designer Background

1. Process: Limestone

2. Developer/licensor: Combustion Engineering

3. Address: 1000 Prospect Hill Road, Windsor, Connecticut 06095

4. Company offering process:

Company: Combustion Engineering

Address: 1000 Prospect Hill Road

Location: Windsor, Connecticut 06095

Company contact: A.J. Snider

Position: Manager, Environmental Control

Telephone number: (203) 688-1911

5. Architectural/engineer:

Company:

Address:

Location:

Company contact:

Position:

Telephone number:

D. Boiler Data

1. Boiler: Lawrence 5

2. Boiler manufacturer: Combustion Engineering

3. Boiler service (base, intermediate, cycling, peak): Cyclic load

4. Year placed in service: 1971

5. Total hours operation (date)::

6. Remaining life of unit:

7. Boiler type: Pulverized coal, (multiple-fuel-design), balanced-draft, tangential-fired

8. Served by stack No.: 5

9. Stack height: 114 m (375 ft)

10. Stack top inner diameter:

11. Unit ratings (MW):

Gross unit rating: 420

Net unit rating without FGD:

Net unit rating with FGD: 400

Name plate rating: ________

12. Unit heat rate:

    Heat rate without FGD: ________

    Heat rate with FGD: 10,900 kJ/kWh (10,300 Btu/kWh)

13. Boiler capacity factor, (1977): 55 to 60

14. Fuel type: Coal

15. Flue gas flow rate:

    Maximum: 600 m^3/s (1,271,000 acfm)

    Temperature: 149°C (300°F)

16. Total excess air: 18 to 20

17. Boiler efficiency: ________

E. Coal Data

1. Coal supplier(s):

    Name(s): ________

    Location(s): ________

    Mine location(s): Near Medicine Bow

    County, State: Wyoming

    Seam: ________

2. Gross heating value: 23,260 kJ/kg (10,000 Btu/lb)

3. Ash (dry basis): 9.8

4. Moisture: 11.8

5. Sulfur (dry basis): 0.55 (as received)

6. Chloride: 0.03

7. Ash composition (See Table A1)

Table A1

Constituent	Percent weight
Silica, SiO_2	38.0
Alumina, Al_2O_3	23.9
Titania, TiO_2	
Ferric oxide, Fe_2O_3	9.5
Calcium oxide, CaO	13.2
Magnesium oxide, MgO	3.5
Sodium oxide, Na_2O	
Potassium oxide, K_2O	
Phosphorous pentoxide, P_2O_5	
Sulfur trioxide, SO_3	
Other	
Undetermined	

F. Atmospheric Emission Regulations

1. Applicable particulate emission regulation
   a) Current requirement: 43 ng/J (0.1 lb/10^6 Btu)
      Regulation and section: ______
   b) Future requirement: ______
      Regulation and section: ______
2. Applicable SO_2 emission regulation
   a) Current requirement: 215 ng/J (0.5 lb/10^6 Btu)
      Regulation and section No.: ______
   b) Future requirement: ______
      Regulation and section: ______

G. Chemical Additives: (Includes all reagent additives - absorbents, precipitants, flocculants, coagulants, pH adjusters, fixatives, catalysts, etc.)

1. Trade name: Limestone

   Principal ingredient: Calcium carbonate (93%), silicas (6%), magnesium carbonate (1%)

   Function: Absorbent

   Source/manufacturer: N.R. Hamm Company

   Quantity employed: __________

   Point of addition: Reaction tank

2. Trade name: __________

   Principal ingredient: __________

   Function: __________

   Source/manufacturer: __________

   Quantity employed: __________

   Point of addition: __________

3. Trade name: __________

   Principal ingredient: __________

   Function: __________

   Source/manufacturer: __________

   Quantity employed: __________

   Point of addition: __________

4. Trade name: __________

   Principal ingredient: __________

   Function: __________

   Source/manufacturer: __________

   Quantity employed: __________

   Point of addition: __________

5. Trade name: __________

Principal ingredient: __________

Function: __________

Source/manufacturer: __________

Quantity employed: __________

Point of addition: __________

H. Equipment Specifications

1. Electrostatic precipitator(s) Not applicable

Number: __________

Manufacturer: __________

Design removal efficiency: __________

Outlet temperature: __________

Pressure drop: __________

2. Mechanical collector(s) Not applicable

Number: __________

Type: __________

Size: __________

Manufacturer: __________

Design removal efficiency: __________

Pressure drop: __________

3. Particulate scrubber(s) In conjunction with SO_2 absorber

Number: 2

Type: Rectangular-throat, variable-throat, rod-deck venturi

Manufacturer: Combustion Engineering

Dimensions: 1.5 m (5 ft) x 11 m (37 ft)

Material, shell: 316L SS

Material, shell lining: None

Material, internals: 316L SS (rods)

No. of modules per train: One

No. of stages per module: One

No. of nozzles or sprays: 44

Nozzle type: Nonatomizing, fan-type spray

Nozzle size: 235 gpm

Boiler load capacity: 50% each train

Gas flow and temperature: 300 m^3/s (635,000 acfm) at 149 °C (300 °F) each

Liquid recirculation rate: 656 liters/s (10,400 gal/min)

Modulation:

L/G ratio: 2.2 liters/m^3 (16 gal/10^3 acf)

Pressure drop: 2.3 kPa (9.0 in. H_2O)

Modulation:

Superficial gas velocity:

Particulate removal efficiency (design/actual):

Inlet loading:

Outlet loading:

SO_2 removal efficiency (design/actual):

Inlet concentration: 748 ppm

Outlet concentration:

4. SO_2 absorber(s)

Number: Two

Type: Vertical, countercurrent spray towers

Manufacturer: Combustion Engineering

Dimensions:

Material, shell: 316L SS

Material, shell lining: None

Material, internals: Headers of FRP

No. of modules per train: One

No. of stages per module: One level of spray

Packing/tray type: None

Packing/tray dimensions: Not applicable

No. of nozzles or sprays: 48 per module

Nozzle type: Spinner vane

Nozzle size:

Boiler load capacity: 50% each train

Gas flow and temperature: 257 m^3/s (544,000 acfm) at 52 °C (126 °F) each

Liquid recirculation rate: 656 liters/s (10,400 gal/min) each

Modulation:

L/G ratio: 2.6 liters/m^3 (19 gal/10^3 acf) each

Pressure drop: 0.6 kPa (2.5 in. H_2O)

Modulation:

Superficial gas velocity:

Particulate removal efficiency (design/actual): 98.9 (venturi and spray tower combined

Inlet loading:

Outlet loading:

SO_2 removal efficiency (design/actual): 52 (venturi and spray tower combined)

Inlet concentration: See particulate scrubber

Outlet concentration: 359 ppm

5. Wash water tray(s) Not applicable

Number:

Type: ______

Materials of construction: ______

Liquid recirculation rate: ______

Source of water: ______

6. Mist eliminator(s)

Number: Two, one per train

Type: Chevron

Materials of construction: FRP

Manufacturer: ______

Configuration (horizontal/vertical): Horizontal

Number of stages: Two plus one bulk entrainment separator

Number of passes per stage: Three (chevron stage)

Mist eliminator depth: ______

Vane spacing: ______

Vane angles: ______

Type and location of wash system: Intermittent, high-pressure water wash directed to top of bulk entrainment separator and bottom of chevrons.

Superficial gas velocity: ______

Freeboard distance: ______

Pressure drop: ______

Comments: ______

7. Reheater(s): ______

Type (check appropriate category): ______

[X] in-line

[ ] indirect hot air

[ ] direct combustion

[ ] bypass

[ ] exit gas recirculation

[ ] waste heat recovery

[ ] other

Gas conditions for reheat:

Flow rate: 551 m^3/s (1,168,000 acfm)

Temperature: 69°C (156°F)

SO_2 concentration: 359 ppm

Heating medium: Hot water

Combustion fuel: Not applicable

Percent of gas bypassed for reheat: Not applicable

Temperature boost (ΔT): 11°C (20°F)

Energy required: 1.25% of boiler output

Comments: Staggered, circumferential-finned tubes constructed of carbon steel

8. Fan(s)

Number: 2

Type: Induced draft

Materials of construction: Carbon steel

Manufacturer:

Location: Downstream of reheater

Rating:

Pressure drop:

9. Recirculation tank(s):

Number: 1

Materials of construction: Carbon steel

Function: Reaction and recirculation

Configuration/dimensions: 48 ft dia x 31 ft high

Capacity: 2.3×10^6 liters (600,000 gal)

Retention time: 10 min

Covered (yes/no): No

Agitator: 4

10. Recirculation/slurry pump(s):

Number:

Type:

Manufacturer:

Materials of construction:

Head:

Capacity:

11. Thickener(s)/clarifier(s) Not applicable

Number:

Type:

Manufacturer:

Materials of construction:

Configuration:

Diameter:

Depth:

Rake speed:

Retention time:

12. Vacuum filter(s) Not applicable

Number: ____________________

Type: ____________________

Manufacturer: ____________________

Materials of construction: ____________________

Belt cloth material: ____________________

Design capacity: ____________________

Filter area: ____________________

13. Centrifuge(s) Not applicable

Number: ____________________

Type: ____________________

Manufacturer: ____________________

Materials of construction: ____________________

Size/dimensions: ____________________

Capacity: ____________________

14. Interim sludge pond(s)

Number: One (shared by Units 4 and 5)

Description: Unlined pond

Area: 65,000 m^2 (16 acres)

Depth: ____________________

Liner type: ____________________

Location: Onsite

Service Life: 20 yr

Typical operating schedule: ____________________

____

Ground water/surface water monitors: ____________________

____

15. Final disposal site(s)

Number: Two (shared by Units 4 and 5)

Description: Unlined settling ponds

Area: 16,000 m^2 (4 acres); 11[illegible],000 m^2 (28 acres)

Depth:

Location: Onsite

Transportation mode: Pipeline

Service life: 20 yr

Typical operating schedule:

16. Raw materials production

Number: One for Units 4 and 5

Type: Wet ball mill

Manufacturer: KVS

Capacity: 12,000 lbs/h

Product characteristics: 80% <200 mesh particle size,

I. Equipment Operation, Maintenance, and Overhaul Schedule

1. Scrubber(s)

Design life:

Elapsed operation time:

Cleanout method:

Cleanout frequency:

Cleanout duration:

Other preventive maintenance procedures: Soot blower to prevent solids accumulation at wet/dry interface

2. Absorber(s)

Design life: ______

Elapsed operation time: ______

Cleanout method: ______

Cleanout frequency: Maintenance performed as needed

Cleanout duration: ______

Other preventive maintenance procedures: ______

3. Reheater(s)

Design life: ______

Elapsed operation time: ______

Cleanout method: ______

Cleanout frequency: ______

Cleanout duration: ______

Other preventive maintenance procedures: Soot blowers upstream of each reheater

4. Fan(s)

Design life: ______

Elapsed operation time: ______

Cleanout method: ______

Cleanout frequency: Maintenance performed as needed

Cleanout duration: ______

Other preventive maintenance procedures: ______

5. Mist eliminator(s)

Design life: ______

Elapsed operation time: ______

Cleanout method: Wash water sprays

Cleanout frequency: Continuous/intermittent

Cleanout duration: Intermittent spray once per day

Other preventive maintenance procedures: ______

6. Pump(s)

Design life: ______

Elapsed operation time: ______

Cleanout method: ______

Cleanout frequency: ______

Cleanout duration: ______

Other preventive maintenance procedures: ______

7. Vacuum filter(s)/centrifuge(s) Not applicable

Design life: ______

Elapsed operation time: ______

Cleanout method: ______

Cleanout frequency: ______

Cleanout duration: ______

Other preventive maintenance procedures: ______

8. Sludge disposal pond(s)

Design life: ______

Elapsed operation time: ______

Capacity consumed: ______

Remaining capacity: ______

Cleanout procedures: ______________________________

____

J. Instrumentation See text of report

A brief description of the control mechanism or method of measurement for each of the following process parameters:

- Reagent addition: ______________________________

  ____

- Liquor solids content: ______________________________

  ____

- Liquor dissolved solids content: ______________________________

  ____

- Liquor ion concentrations

  Chloride: ______________________________

  ____

  Calcium: ______________________________

  ____

  Magnesium: ______________________________

  ____

  Sodium: ______________________________

  ____

  Sulfite: ______________________________

  ____

  Sulfate: ______________________________

  ____

  Carbonate: ______________________________

  ____

  Other (specify): ______________________________

  ____

- Liquor alkalinity: ______________________________

  ____

- Liquor pH: ______________________________

  ____

- Liquor flow: ______________________________

  ____

- Pollutant (SO_2, particulate, NO_x) concentration in flue gas: ______________________________

  ____

- Gas flow: ______________________________

  ____

- Waste water ______________________________

  ____

- Waste solids: ______________________________

  ____

Provide a diagram or drawing of the scrubber/absorber train that illustrates the function and location of the components of the scrubber/absorber control system.

Remarks: ______________________________

____

____

____

____

K. Discussion of Major Problem Areas:

1. Corrosion: See the main body of the report concerning problem areas

   ____

2. Erosion: See the main body of the report concerning problem areas

3. Scaling: See the main body of the report concerning problem areas

4. Plugging: See the main body of the report concerning problem areas

5. Design problems: See the main body of the report concerning problem areas

6. Waste water/solids disposal: See the main body of the report concerning problem areas

7. Mechanical problems: See the main body of the report concerning problem areas

L. General comments:

APPENDIX C

PLANT PHOTOGRAPHS

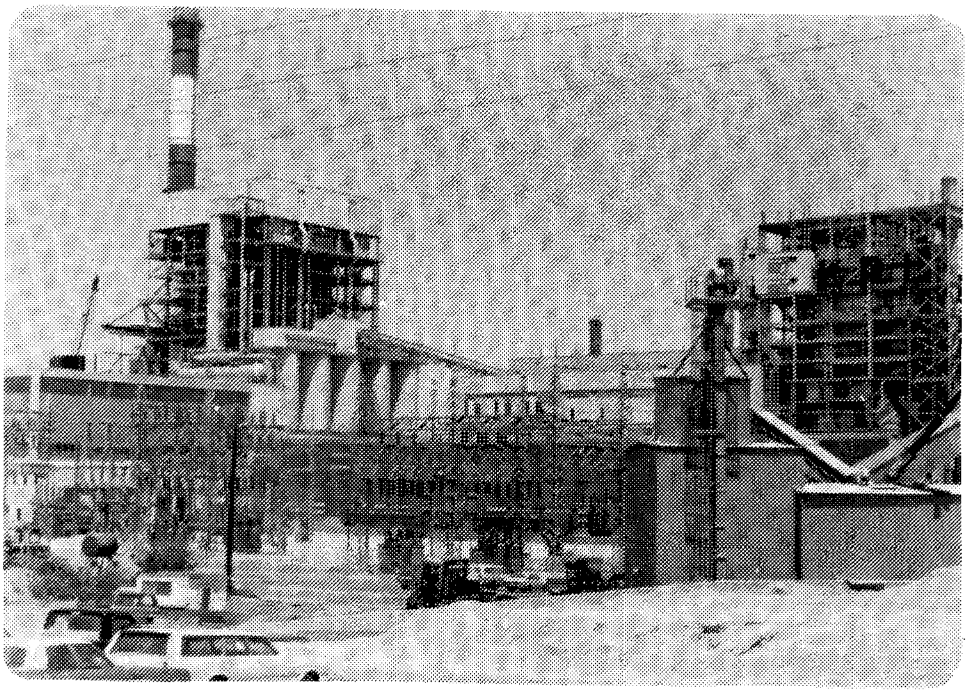

Photo 1. View of Lawrence Energy Center. At left is Lawrence 5, including coal bunkers, steam generator, and carbon steel stack.

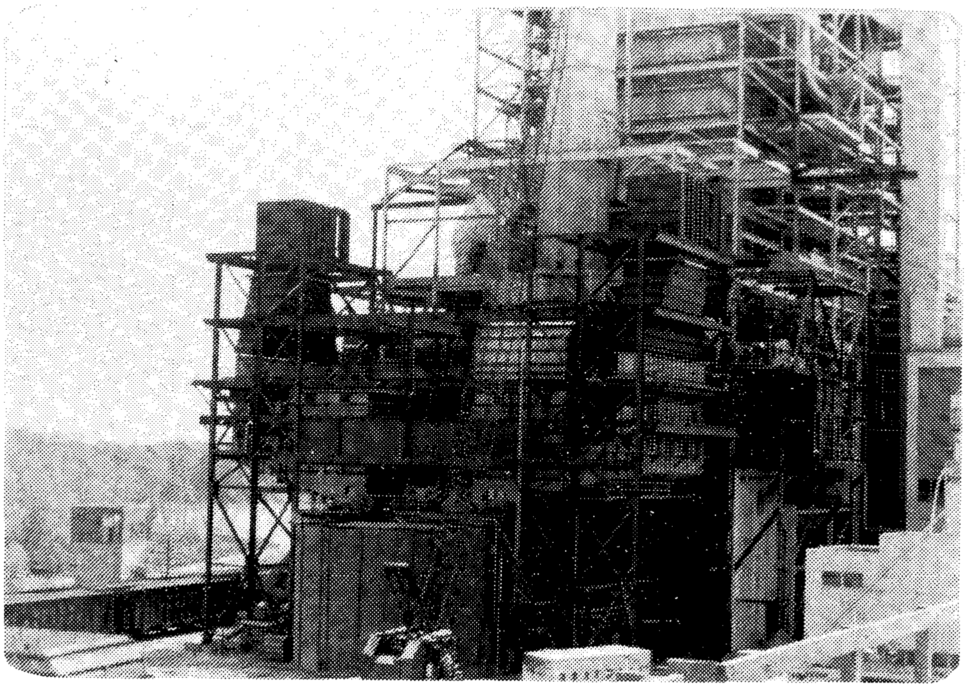

Photo 2. View of new Lawrence 5 scrubbing system under construction. The original marble-bed modules, which are located behind the new modules, remained in service virtually throughout the construction period.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-19[illegible]b	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Survey of Flue Gas Desulfurization Systems: Lawrence Energy Center, Kansas Power and Light Co.		5. REPORT DATE August 1979 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Bernard A. Laseke, Jr.		8. PERFORMING ORGANIZATION REPORT NO. PN 3470-1-C
9. PERFORMING ORGANIZATION NAME AND ADDRESS PEDCo Environmental, Inc. 11499 Chester Road Cincinnati, Ohio 45246		10. PROGRAM ELEMENT NO. EHE624 11. CONTRACT/GRANT NO. 68-02-2603, Task 24
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 7/78 - 12/78 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Norman Kaplan, Mail Drop 61, 919/541-2556. EPA-650/2-75-057e is an earlier report on this same station.

16. ABSTRACT

This report describes the results of a survey of operational flue gas desulfurization (FGD) systems on coal-fired utility boilers in the United States. The FGD systems installed on Units 4 and 5 at the Lawrence Energy Center of the Kansas Power and Light Company is described in terms of design and performance. The FGD system installed on each unit consists of two parallel two-stage scrubber modules, each of which includes a rectangular, variable-throat rod-deck venturi scrubber arranged in series with a spray tower absorber. Each system is also equipped with slurry-hold tanks, mist eliminators, and in-line reheaters, as well as isolation and bypass dampers. The two systems share a common limestone storage and preparation facility and waste-disposal facility. These FGD systems represent a second generation design replacement of limestone furnace-injection and tail-end scrubbing systems which were originally installed on Units 4 and 5 in 1968 and 1971, respectively. The original systems operated approximately 27,000 hours and 23,000 hours on coal-fired flue gas for Units 4 and 5, respectively. The redesigned FGD system on Unit 4 went into service in early January 1977. The Unit 5 FGD system went into service on April 14, 1978.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Scrubbers	Air Pollution Control	13B	
Flue Gases	Coal	Stationary Sources	21B	21D
Desulfurization	Combustion	Wet Limestone	07A,07D	
Fly Ash	Cost Engineering	Particulate		14A
Limestone	Sulfur Dioxide			07B
Slurries	Dust Control		11G	
Ponds			08H	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Unlimited	Unclassified	123
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)