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Survey of Flue Gas Desulfurization Systems:
Duck Creek Station, Central Illinois Light Co.

Interagency Energy/Environment R&D Program Report

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EPA REVIEW NOTICE

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Survey of Flue Gas Desulfurization Systems: Duck Creek Station, Central Illinois Light Co.

by

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ACKNOWLEDGMENT

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

Mr. Norman Kaplan, EPA Project Officer, had primary responsibility within EPA for this project report. Larry Haynes, Environmental Manager, Central Illinois Light Company, provided information on plant design and operation.

SUMMARY

The Duck Creek plant is a new coal-fired power-generating station owned and operated by the Central Illinois Light Company (CILCo). It is situated in an unreclaimed strip-mining area near Canton, Illinois. The current capacity of the plant with one coal-fired power-generating unit is 416 MW (gross). Duck Creek 1, the existing unit, was placed in commercial service on June 1, 1976. Duck Creek 2, 3, and 4 are three planned additional units of similar capacity scheduled for commercial operation in 1982, 1989, and 1992, respectively. This will bring the total station capacity to approximately 2000 MW.

Duck Creek 1 fires a high-sulfur, bituminous-grade, Illinois coal having maximum sulfur and ash contents of 4.0 and 18.0 percent. To enable the unit to meet Federal New Source Performance Standards, it is equipped with an emission control system for particulate and sulfur dioxide control.

Primary particulate control is provided by two parallel electrostatic precipitators (ESP's) with a design removal efficiency of 99.8 percent. The ESP's are supplied by Pollution Control-Walther. Primary sulfur dioxide control is provided by a limestone flue gas desulfurization (FGD) system consisting of four parallel 25 percent-capacity scrubbing modules with a total removal efficiency of 85 percent. The FGD system is supplied by Riley Stoker/Environeering.

The utility originally planned to install only one 25 percent capacity (100-MW equivalent) scrubbing module to conduct a thorough high sulfur coal test program. The data obtained was to have been used to design the remaining three modules. Approval of this plan, which was originally granted at the State level,

was later revoked by the U.S. EPA, which required the entire plant to comply with New Source Performance Standards. A consent decree granted CILCo by the EPA gave the utility a variance to burn high sulfur coal from July 1, 1976, to April 1, 1977. During this period, one scrubber module (completed by June 1976) would remain in the gas path and remove sulfur dioxide from 25 percent of the boiler flue gas. The timetable for the installation of the remaining modules was accelerated to August 1978. During the interim period between the end of the variance and the completion of the remaining modules, low sulfur coal would be burned in the boiler in order to comply with standards.

The first scrubbing module was placed in service on July 1, 1976, and operated intermittently throughout the remainder of the year and for approximately one month in early 1977. Several problems, including plugging, scaling, corrosion, and materials failure, were encountered during this period. As a result of this initial operating experience, CILCo and Riley Stoker/Environeering made some design changes to both the existing and planned scrubbing modules during the April 1977 to August 1978 period when low sulfur coal was burned. On July 23, 1978, the three remaining scrubbing modules were completed and all four modules were placed in the gas path for treatment of high sulfur coal flue gas.

Central Illinois Light Company reported the total capital cost of the system to be \$37,540,000, including \$33,740,000 for the system and all ancillary equipment and \$3,800,000 for the sludge disposal pond. Based on a unit gross generating capacity of 416 MW, this amounts to \$90.2/kW. Actual annual cost figures are not yet available; however, based on the limited operation of one module, CILCo estimates that total annual cost will be \$13,921,000, including \$7,539,000 for variable charges and \$6,382,000 for fixed charges. Based on a net unit rating of 400 MW and a capacity factor of 65 percent, this amounts to 6.11 mills/kWh.

Table 1 summarizes data on the facility and the FGD system.

TABLE 1. DATA SUMMARY: DUCK CREEK 1

Gross rating, MW	416
Net rating, MW	400
Fuel	Coal
Average fuel characteristics:[a]	
Heating value, kJ/kg (Btu/lb)	24,523 (10,543)
Ash, percent	9.12
Moisture, percent	18.0
Sulfur, percent	3.30
Chloride, percent	0.03
FGD process	Limestone
FGD system supplier	Riley Stoker/ Environeering
Application	New
Status	Operational
Startup dates:	
Initial[b]	July 1976
Commercial	August 1978
Design removal efficiency, percent	
Particulate[c]	99.8
Sulfur dioxide	85.3
Makeup water, liters/min per MW (gal/min per MW)[d]	5.65 (1.49)
Economics	
Capital, $/kW (gross)	90.2
Annual, mills/kWh (net)	6.11

[a] Design fuel specifications for high sulfur Illinois coal.

[b] Boiler and ESP commenced operation in June 1976. One FGD module commenced operation in July 1976. Full commercial operation with all four FGD modules commenced in August 1978.

[c] Particulate removal provided by ESP's.

[d] Design makeup water requirements.

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 Duck Creek plant of the Central Illinois Light Company (CILCo). It includes pertinent process design and operating data, a description of major startup and operational problems and solutions, atmospheric emissions data, and capital and annual cost information.

This report is based on information obtained during and after a plant inspection conducted for PEDCo Environmental personnel on June 9, 1977, by CILCo. The information presented in this report is current as of October 1978.

Section 2 provides information and data on facility design and operation; Section 3 provides background information and a detailed description of the FGD process; Section 4 describes and analyzes the operation and performance of the FGD system. Appendices A and B contain details of plant and system operation, economic data, and photos of the installation.

SECTION 2

FACILITY DESCRIPTION

The Duck Creek plant is a new coal-fired power-generating station owned and operated by CILCo. Located in Fulton County, Illinois, approximately 65 km (40 mi) southwest of Peoria, the plant site consists largely of unreclaimed strip-mining land situated in a relatively flat, rural area. There are no other major industrial facilities within the immediate area. The nearest population center is Canton (a town of about 14,000 people), which is approximately 8 km (5 mi) southwest of the plant.

The plant site proper covers an area of approximately 36 km^2 (9000 acres), approximately 4 km (2.5 mi) from the Illinois River. Duck Creek, an intermittent stream carrying only the runoff from the immediate watershed, runs through the site. The plant's cooling pond was created by constructing an earthen dam across this creek. The dam, which is a zoned earthwork structure with a crest length of 520 meters (1700 ft) and a maximum height of 37 meters (120 ft), forms a reservoir covering an area of approximately 7.36 km^2 (1820 acres). The powerhouse is located in an unmined section that is capable of withstanding the heavy loads associated with the powerplant equipment and foundations. At the present time two coal mines on the site remain active. A general overview of the Duck Creek plant site, including all major facilities, accesses, and waterways, is provided in Figure 1.

Duck Creek 1 is equipped with its own steam generator and turbine. The dry-bottom, pulverized-coal-fired steam generator is a balanced-draft, front-fired, single reheat unit supplied

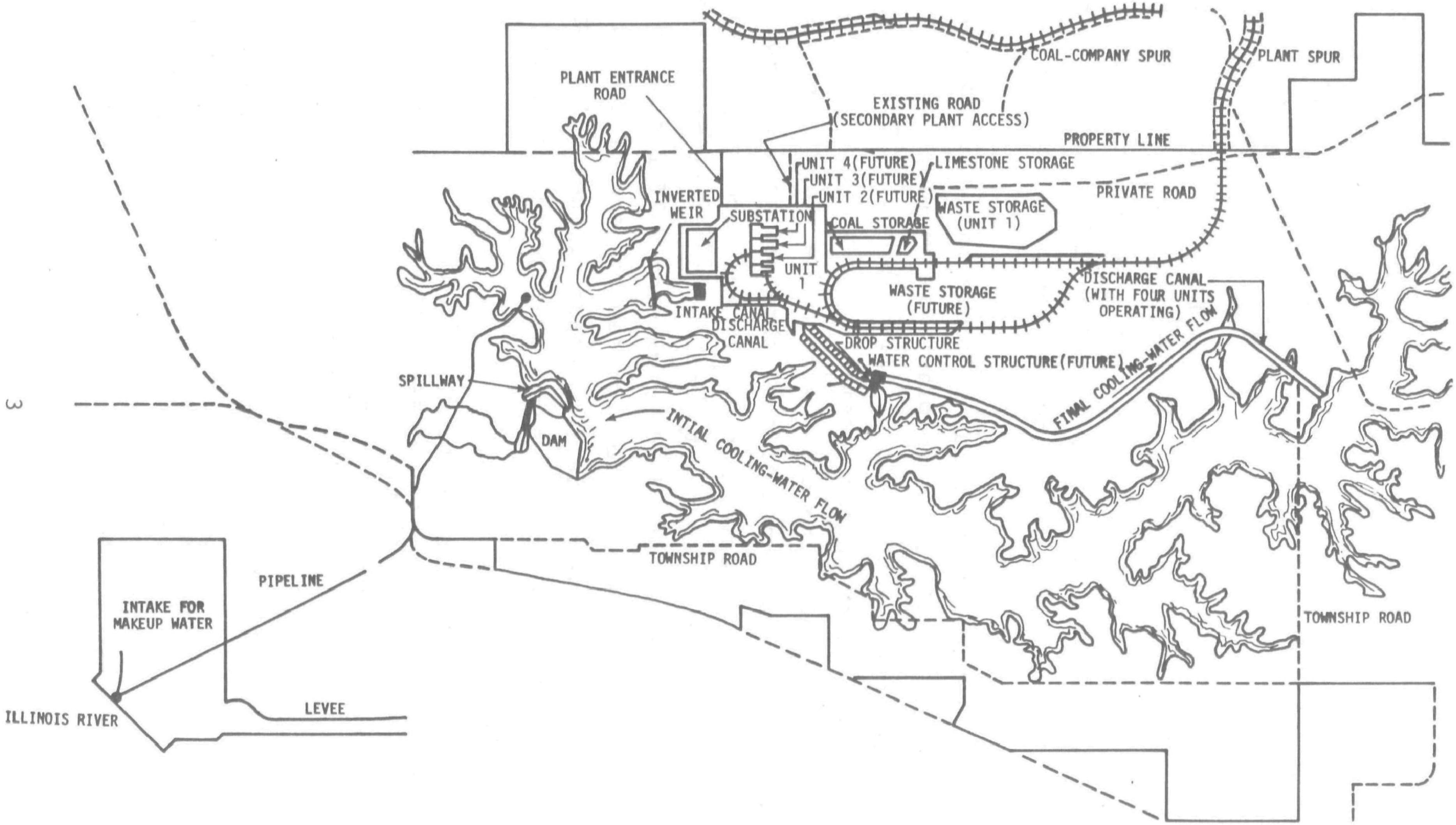

Figure 1. Overview of Duck Creek plant, including all major facilities, accesses, and waterways.

by Riley Stoker. It produces 1360 Mg (3,000,000 lb) per hour of superheat steam at 540°C (1005°F) and 18 MPa (2600 psig), and 1110 Mg (2,450,000 lb) per hour of reheat steam at 540°C (1005°F) and 3.3 MPa (481 psig). The turbine generator is a 416-MW (gross), 17-MPa (2400 psig), 538°C (1000°F), 3.4-kPa (1.0 in. Hg), 3600-rpm unit supplied by General Electric. The station also contains one auxiliary boiler, which is used for plant startups or for powering a house turbine generator. The auxilary boiler, a shop-assembled unit supplied by Riley Stoker, fires No. 2 fuel oil and produces 23 Mg (50,000 lb) per hour of steam at 1.8 MPa (250 psig).

The plant burns high sulfur Illinois coal and low sulfur Colorado coal. Originally, the plant was designed to burn only a high sulfur bituminous grade of Illinois coal. This coal is supplied primarily by United Freeman's Crown and Buckheart mines in Fulton County, near the plant site. The plant also burns a low sulfur bituminous grade of coal obtained on a spot-purchase basis from several Colorado mines. It was necessary to find a low sulfur coal supply source to enable the plant to meet Federal New Source Performance Standards regarding sulfur dioxide emissions during the interim period between the end of the variance (April 1, 1977) and commercial operation of the entire FGD system (August 1, 1978). Table 2 presents average characteristics of these coals.

TABLE 2. CHARACTERISTICS OF COAL FIRED AT DUCK CREEK

Source	Characteristics	Value (average)
Illinois	Heating value, kJ/kg (Btu/lb)	24,523 (10,543)
	Ash, percent	9.12
	Moisture, percent	18.0
	Sulfur, percent	3.3
	Chloride, percent	0.03
Colorado	Heating value, kJ/kg(Btu/lb)	24,750 (10,640)
	Ash, percent	6.97
	Sulfur, percent	0.41

A highly flexible coal-handling system capable both of providing for the ultimate plant capacity of 2000 MW (net) and of transporting limestone for the FGD system was developed for Duck Creek. The flexibility of the coal-handling system was provided by extending the stacker/reclaimer's travel some 90 m (300 ft), thereby allowing additional space for limestone storage. A series of interlocks is included in the system to minimize the possibility of accidently conveying coal to the limestone area or limestone to the coal area.

The coal/limestone handling system is designed to accommodate deliveries by rail, but it also includes provisions for truck shipments because of the potential for barge unloading on the Illinois River. Coal or limestone can be conveyed from the unloading area to the yard storage area or directly to the plant at a maximum rate of 1.8 Gg (2000 tons) per hour. Coal or limestone diverted to yard storage is deposited in either live or dead storage piles. Coal or limestone going directly to the plant is transported by separate conveyors after passing through a switch house. Limestone is conveyed on a single 1.8-Gg (2000-ton) belt to the crushing and milling building, whereas the coal is transferred to the breaker house and sample house before being burned in the boiler. Figure 2 illustrates the major components of the Duck Creek coal/limestone handling network.

To meet Federal New Source Performance Standards, Duck Creek 1 is equipped with an emission control system that includes electrostatic precipitators (ESP's) and an FGD system. Primary particulate control is provided by two parallel, cold-side ESP's supplied by Pollution Control-Walther and designed to remove 99.8 percent of the inlet particulate matter. Primary sulfur dioxide control is provided by four parallel, wet-limestone, rod-deck (Ventri-Sorber) scrubber modules supplied by Riley Stoker/Environeering and designed to remove 85 percent of the inlet sulfur dioxide. All or part of the flue gas can be bypassed around the scrubber modules by manipulating bypass dampers and module

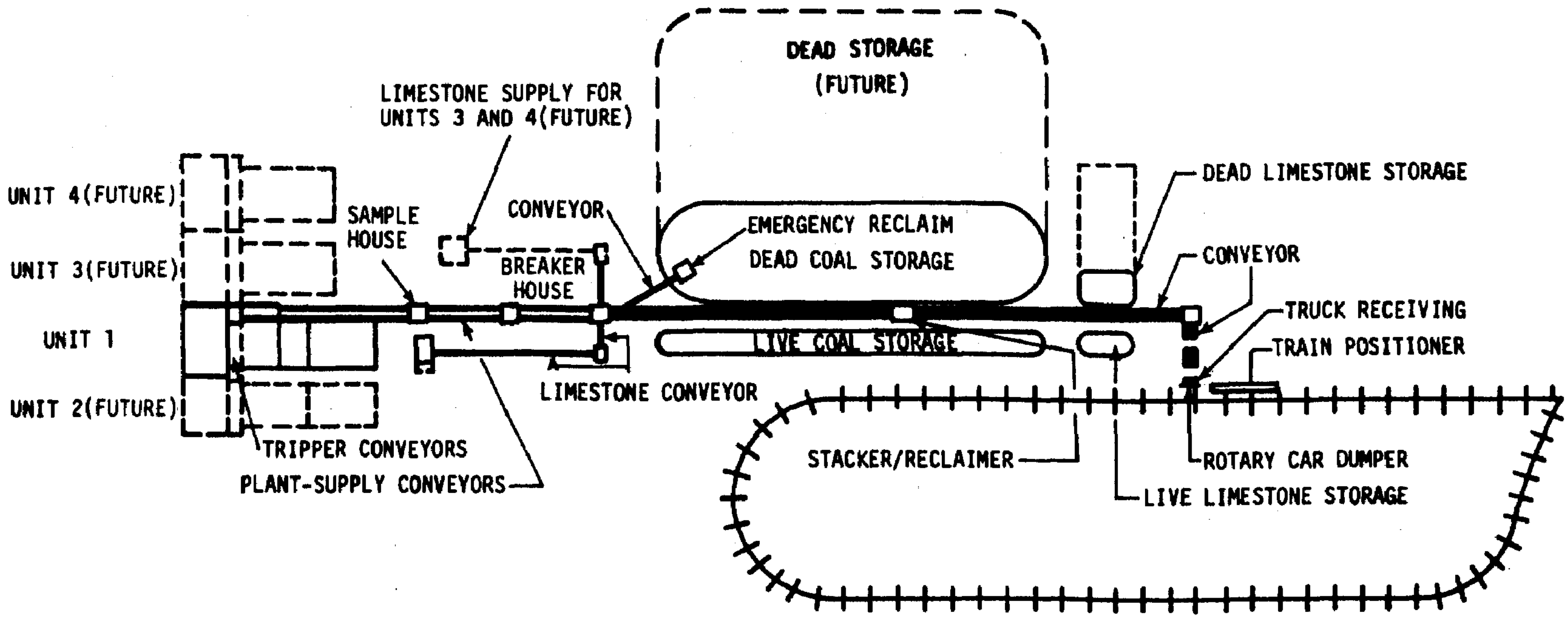

Figure 2. Major components of the coal/limestone handling network at the Duck Creek plant.

isolation dampers. The bottom ash, fly ash, and scrubbing wastes are disposed of in an onsite 65-acre sludge pond lined with a natural impermeable material.

The Federal Clean Air Act of 1972 limits particulate and sulfur dioxide emissions to 43 ng/J (0.1 $lb/10^6$ Btu) and 516 ng/J (1.2 $lb/10^6$ Btu) of heat input to the boiler. Actual particulate emissions, as measured by the utility during performance tests, ranged from 47.6 mg/m^3 (0.0208 gr/scf) to 191.5 mg/m^3 (0.0837 gr/scf).* Actual sulfur dioxide emissions, as measured by the utility during performance tests,† were approximately 252 ppm. Based on an inlet concentration of 3000 ppm from the combustion of 3.3 percent sulfur coal, this translates into an FGD system removal efficiency of 91.6 percent, which is above the 85.3 percent design removal efficiency for 4.0 percent sulfur coal.

Figure 3 provides a process flow diagram of Duck Creek 1, including the power plant, emission control system, reagent preparation facility, and sludge disposal area. Table 3 presents data on plant design, operation, and atmospheric emissions.

* All measurements are expressed on dry basis.

† Performed during single module operation conducted from July 1976 to April 1, 1977.

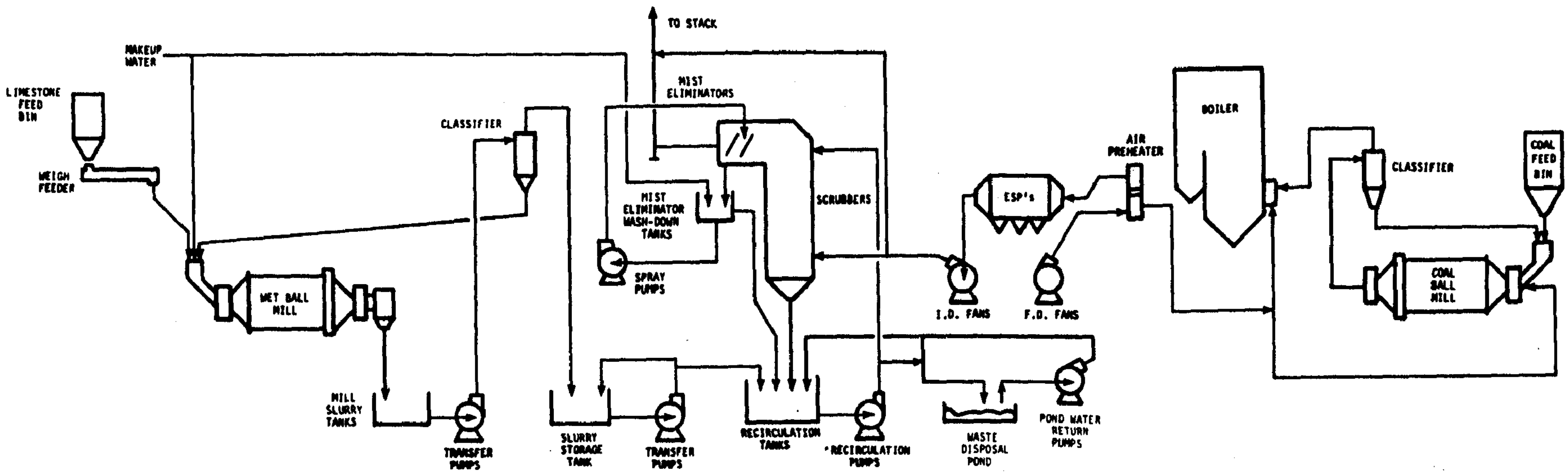

Figure 3. Simplified process flow diagram of Duck Creek 1 power plant and emission control system.

TABLE 3. DESIGN, OPERATION, AND EMISSION DATA: DUCK CREEK 1

Generating capacity, MW:	
Gross	416
Net without FGD	410
Net with FGD	400
Maximum coal consumption, Mg/h (tons/h)	174 (192)
Maximum heat input, GJ/h (10^6 Btu/h)	4,265 (4,040)
Maximum flue gas rate, m^3/s (acfm)	668 (1,415,610)
Flue gas temperature, °C (°F)	135 (275)
Unit heat rate, kJ/net kWh (Btu/net kWh)	10,380 (9,840)
Unit capacity factor, percent (1977)	55 - 60
Emission controls:	
Particulate	Electrostatic precipitators
Sulfur dioxide	Rod-deck scrubbers
Particulate emission rate:	
Limit, ng/J (lb/10^6 Btu)	43 (0.1)
Actual, mg/m^3 (gr/scf)	47.6 - 191.5 (0.0208-0.0837)
Sulfur dioxide emission rate:	
Limit, ng/J (lb/10^6 Btu)	516 (1.2)
Actual, ppm	252 [a]

[a] Measurement obtained during single module operation conducted from July 1976 to April 1, 1977.

SECTION 3

FLUE GAS DESULFURIZATION SYSTEM

BACKGROUND INFORMATION

Because environmental constraints prevented expansion of their existing plants, in the late 1960's CILCo began searching for locations that were capable of ultimately supporting 2000 MW of coal-fired capacity and included an onsite pond-treatment facility for cooling purposes. By early 1970 the search was narrowed to three possible sites. After determining the Duck Creek site to be the best of the three, CILCo officials commissioned a thorough feasibility study to determine representative cost estimates for plant construction, including the use of a cooling pond. This feasibility study indicated that the Duck Creek site could support the ultimate plant capacity and that the use of a cooling pond offered substantial capital and annual cost savings over mechanical- and natural-draft cooling towers.

Compliance with New Source Performance Standards governing sulfur dioxide and particulate emissions was also considered at this stage of development. Investigations revealed that compliance with particulate emission regulations could readily be achieved with the use of ESP's or scrubbers. Compliance with sulfur dioxide emission regulations, however, would be more difficult. Two basic alternatives were considered: burning low sulfur western coal or burning high sulfur coal and installing FGD equipment. The former alternative was rejected for several reasons, including the premium paid for low sulfur coal; higher transportion costs; the presence of abundant supplies of cheap, high sulfur coal in mines near the plant site; and the adverse effect of low sulfur coal on ESP performance.

Two emission control strategies were evaluated for high sulfur coal application: two-stage particulate and sulfur dioxide wet scrubbing and an ESP-FGD combination for separate collection of particulate and sulfur dioxide. The ESP-FGD alternative was given primary consideration because it would (1) result in a capital cost saving of $2,000,000, (2) reduce auxiliary power requirements by 10 MW, (3) reduce total annual cost, (4) offer greater mechanical reliability, and (5) make it possible to bypass the FGD modules during forced outages without reducing the boiler load.

In 1972 and 1973 CILCo and Riley Stoker (the boiler supplier for Duck Creek 1) initiated an intensive program to evaluate various FGD processes and designs that could be used in conjunction with an ESP for high sulfur coal service. In late 1972 a bench-scale program employing a 0.7-m^3/s (1500-acfm)* laboratory test unit was conducted. This program involved the use of a new, patented scrubber design developed by Environeering (formerly National Dust Collector), a firm later acquired by Riley Stoker. Originally, Environeering held patents (which expired in early 1972) on a marble-bed design (Marble Bed hydro-filter). Prior to the expiration of these patents, however, Environeering had developed a new, patented design using rod-decks in a vertical, countercurrent spray tower (Ventri-Sorber scrubber). The bench-scale results (summarized in Table 4) were very encouraging. Using limestone slurry, this spray tower achieved sulfur dioxide removal efficiencies in the 80 to 88 percent range on inlet concentration levels of 2000 to 3000 ppm at pressure drops of 2.1 kPa (8.5 in. H_2O).

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* 0.5 MW equivalent electrical capacity.

TABLE 4. DUCK CREEK 1 FGD SYSTEM BENCH-SCALE TEST RESULTS

Parameters	Test conditions Block 1	Block 2
Gas flow rate, m^3/min (acfm)	48 (1700)	48 (1700)
Liquid flow rate, liters/s (gal/min)	5.4 (85)	5.4 (85)
Pressure drop, kPa (in. H_2O)	2.1 (8.5)	2.1 (8.5)
Liquid/gas ratio, liters/m^3 (gal/10^3 acf)	6.7 (50)	6.7 (50)
Sulfur dioxide inlet concentration, ppm	2000	3000
Sulfur dioxide outlet concentration, ppm	238	555
Sulfur dioxide removal efficiency, percent	88.1	81.5

As a result of this successful bench-scale test program, a 185 m^3/min (6500 cfm) limestone pilot plant costing over $1 million was installed and operated from March 1973 to December 1973 at CILCo's E.D. Edwards Station. The pilot plant included a rod-deck scrubber and all the related equipment, which was tied into the duct work of Edwards 3, a coal-fired unit that included an ESP for primary particulate control. During the course of this 9-month test program, the pilot operated over 5100 hours on boiler flue gas and achieved sulfur dioxide removal efficiencies above 90 percent on 2 to 3 percent sulfur coal. The most significant information gained from this plant concerned construction materials. Originally, the pilot scrubber, including all internals and rods, was constructed of unlined carbon steel. Widespread corrosion and ultimate failure of the carbon steel shortly after the outset of the program necessitated replacement of the internals and rods with Hastelloy G and 316L stainless steel. The results of the Edwards pilot plant program are summarized in Table 5.

TABLE 5. RESULTS OF THE E. D. EDWARDS PILOT PLANT TEST PROGRAM

Gas capacity	
Nominal, m^3/min (ft^3/min)	185 (6500)
Maximum, m^3/min (ft^3/min)	193 (6800)
Application	Coal-fired flue gas
Period of performance	Mar. 1973 - Dec. 1973
Total operation time, h	5100
Coal sulfur, percent	2.0 - 3.0
Sulfur dixoide inlet concentration, ppm	2000
Pressure drop, kPa (in. H_2O)	2.1 (8.6)
Liquid recirculation rate, liters/s (gal/min)	20.5 (325)
Liquid/gas ratio, liters/m^3 (gal/1000 acf)	6.7 (50)
Sulfur dixoide outlet concentration, ppm	170
Sulfur dioxide removal efficiency, percent	91.5

In November 1974, following the completion of the Edwards pilot plant test program, CILCo awarded Riley Stoker/Environeering a contract to supply a limestone FGD system for Duck Creek 1. The contract originally specified that only one module having a 25 percent gas capacity (100 MW) be installed for testing and evaluation on high sulfur coal. The remaining three modules would be installed at a later date, and any design modifications dictated by the module evaluation program would be incorporated. This approach was eventually rejected by the U.S. EPA, and in August 1976 CILCo awarded Riley Stoker/Environeering a contract to supply the remaining three modules for operation by August 1, 1978.

PROCESS DESCRIPTION

The limestone slurry FGD system operating at Duck Creek was designed, fabricated, and installed by Riley Stoker/Environeering in accordance with specifications by Gilbert/Commonwealth Associates for operating conditions and equipment requirements. The FGD system consists of four parallel rod-deck scrubber modules designed to treat the entire boiler flue gas stream of 668 m^3/s (1,415,600 acfm) at 135°C (275°F). The FGD system includes limestone storage, preparation, and handling equipment; a duct work and damper arrangement; waste disposal and pond water return equipment; and service water and compressed air equipment.

The Duck Creek FGD system can be conveniently described in terms of six basic operations: (1) limestone preparation, (2) limestone slurry handling, (3) gas treatment, (4) mist elimination, (5) gas bypass, and (6) solids disposal and water return.

Limestone Preparation

Limestone for FGD operations is supplied by the Columbia Quarry Company in Valmeyer, Illinois, approximately 320 km (200 mi) from the plant site. The limestone is delivered to the plant by rail as 1.9 cm x 0 cm (3/4 in. x 0 in.) rock containing no less than 95 percent calcium carbonate. The limestone is stored in a feed bin with a 24-h supply capacity and transferred to a wet ball mill, where it is ground by a weigh feeder at a maximum rate of 36 Mg (40 tons) per hour. The limestone is ground to a 90 percent minus 200-mesh powder and the slurried effluent from the mill is discharged to a mill slurry tank, which is a collection sump that serves as a reservoir for the slurry pumps. The slurry pumps discharge the milled limestone to a classifier at a rate of 50 liters/s (800 gal/min). The oversize stone (exceeding 90 percent through 200 mesh) is returned to the front of the mill for regrinding. Overflow from the classifier returns to the mill slurry tank. The effluent from the milling system consists of a 35 to 40 percent solids limestone slurry. Figure 4 is a simplified diagram of the Duck Creek limestone preparation system.

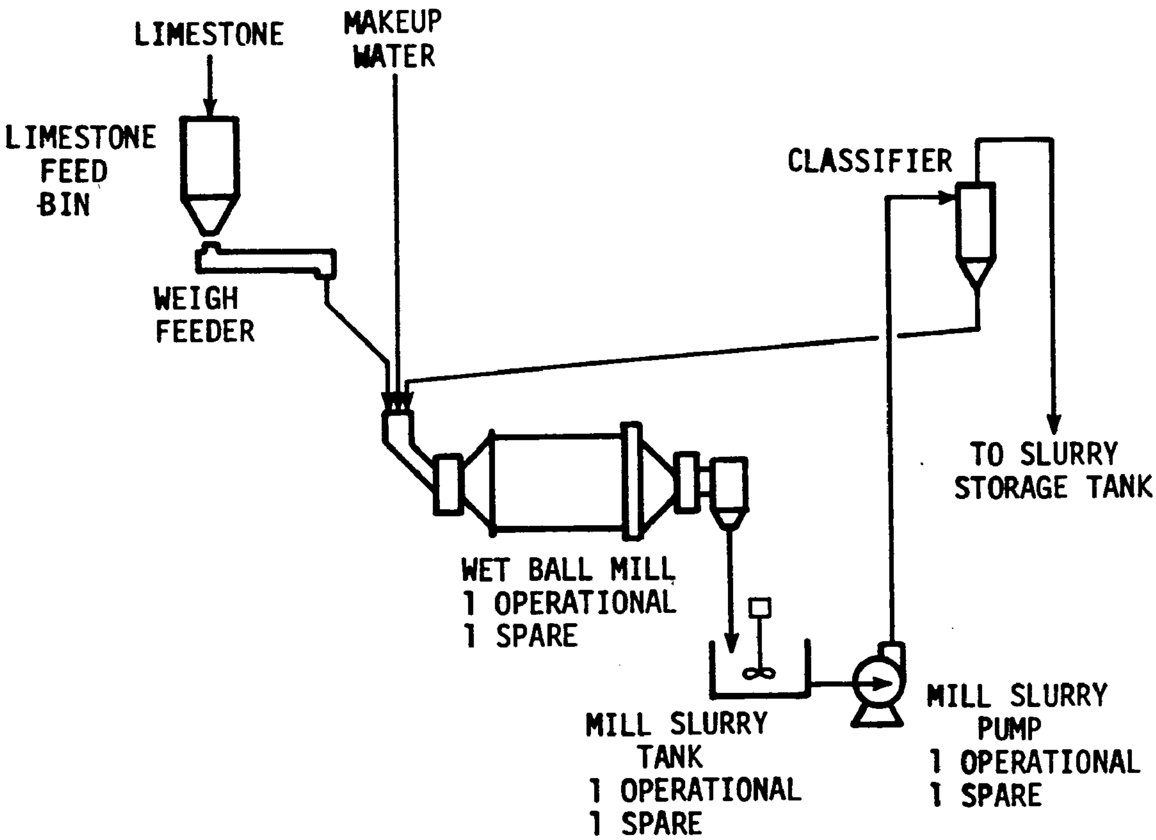


Figure 4. Duck Creek 1 FGD limestone storage and preparation facility.

Limestone Slurry Handling

The ground limestone slurry (35 to 40 percent solids) from the milling operation is stored in a 301,000-liter (79,500-gal) agitated storage tank. Two agitators, one operational and one spare, maintain slurry suspension and prevent settling. The slurry is transferred from the storage tank to the pumphouse through a continuous-feed supply manifold that feeds back to the storage tank. Taps off the return pipe provide a flow of slurry to each recirculation tank for use in the scrubbing module or back to the mill slurry tank.

The limestone slurry tapped from the storage tank return loop is added to the liquid scrubbing circuit of each module through a recirculation tank, which is an agitated, 606,000-liter (160,000-gal) vessel that receives fresh limestone slurry from the storage tank, spent solution from the scrubber module, and return water from the pond. Recirculation-tank slurry is continuously pumped from the base of the recirculation tank through three 51-cm (20-in.) diameter lines to 12 spray heads located at the top of each scrubber module. Pumping capacity is provided by two 497 liters/s (7875 gal/min) operational pumps (one spare per module). Discharge from the spray heads flows down through the scrubber module, contacting the gas flowing upward through the rod decks. Spent solution flows by gravity to the recirculation tank, where chemical reactions are completed and reaction products and unused reagent are collected. Spent slurry is bled from the recycle tank by a line off the recirculation pump discharge header. Figure 5 shows a simplified diagram of the Duck Creek FGD system liquid scrubbing circuit, including limestone slurry handling, scrubbing, and recirculation.

Gas Treatment

The flue gas exits the boiler at 1140 m^3/s (2,415,000 acfm) and 446°C (835°F) at full load, then passes through half-size air preheaters before entering two Pollution Control-Walther ESP's connected in parallel. Each ESP treats 50 percent of the total

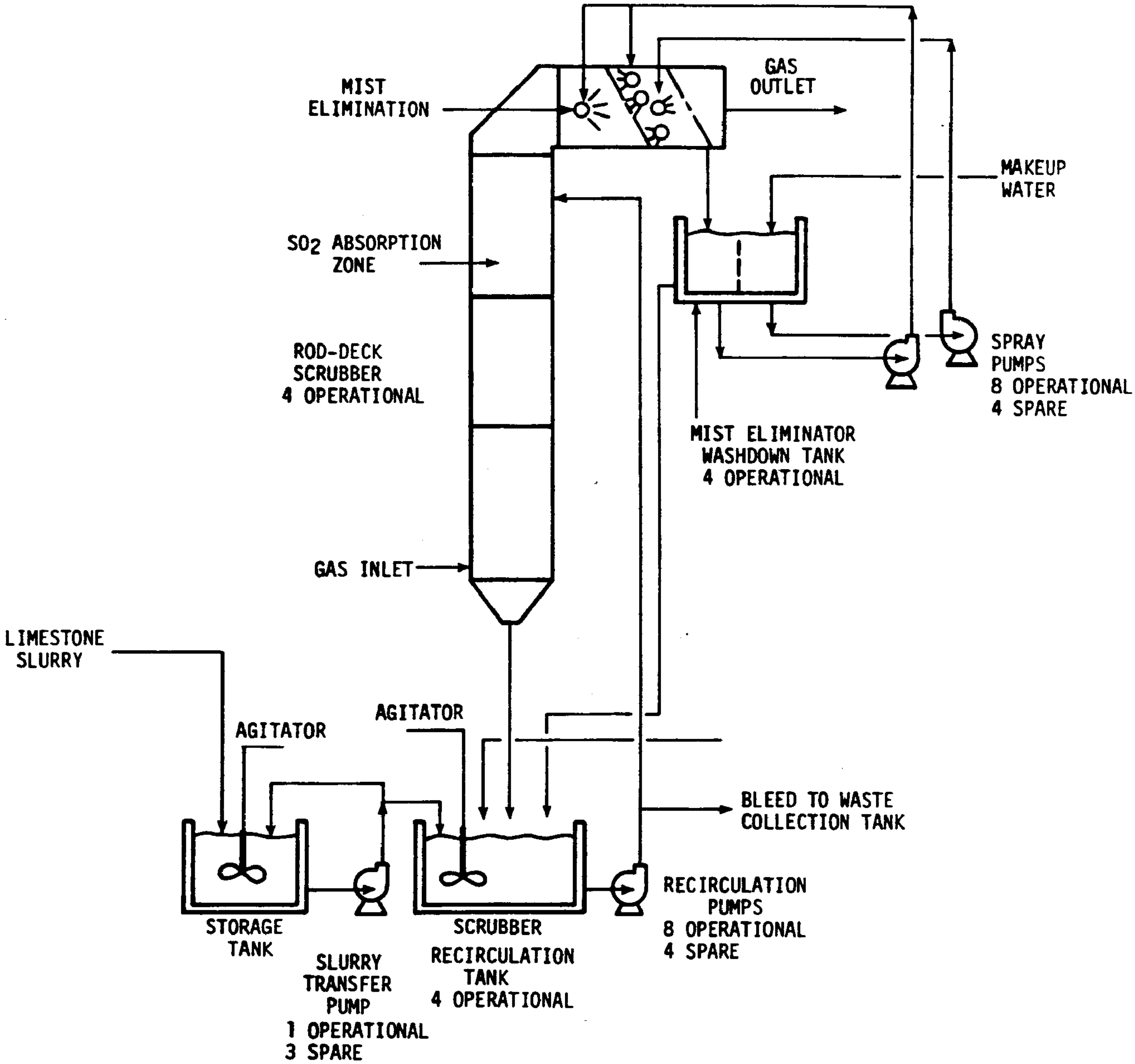


Figure 5. Duck Creek 1 FGD system scrubbing circuit.

gas flow. The ESP's are designed to remove 99.8 percent of the inlet particulate when the inlet gas loading is 14.5 mg/m^3 (6.34 gr/scf). The discharge gas from the ESP's enters a manifold supplying four induced-draft fans. These fans overcome draft loss in the boiler as well as in the ESP's and FGD system. They are connected in parallel to a common duct that distributes the gas to each scrubber module in the FGD system or to the bypass duct.

Flue gas enters the base of each scrubber module, where it is quenched to adiabatic saturation conditions. The quenched gas flows upward through nine successive stages of rod decks, where it contacts the scrubbing slurry in a countercurrent fashion. The scrubbing slurry sprayed from the top of each module flows downward through the rod decks. The rod decks provide intimate gas/slurry contacting sites that enhance mass transfer of the sulfur dioxide into the liquid phase, thus promoting sulfur dioxide removal.

The cleaned, saturated gas stream in each module then exits the spray zone, turns 90 degrees, and passes through horizontal mist eliminators, where entrained droplets of moisture and slurry are removed. The discharge duct from each module feeds gas into the breeching, through which it enters the stack approximately 20 m (65 ft) above grade. Figure 6 provides a cutaway view of the rod-deck scrubber and mist eliminator used in the Duck Creek FGD system.

Scrubbed, saturated gas exits the FGD system and enters the stack through the breeching section without benefit of reheat. The "wet stack" is a 150-m (500-ft) chimney with a Cor-Ten steel flue lined with flake glass. Four bottom hoppers are included in the stack for collection of moisture and slurry droplets that fall out of the flue gas because of a difference in the velocities of the droplets and the gas.

Gas Bypass

The FGD system is equipped with a complex network of ducts and dampers that allows part or all of the flue gas to bypass any

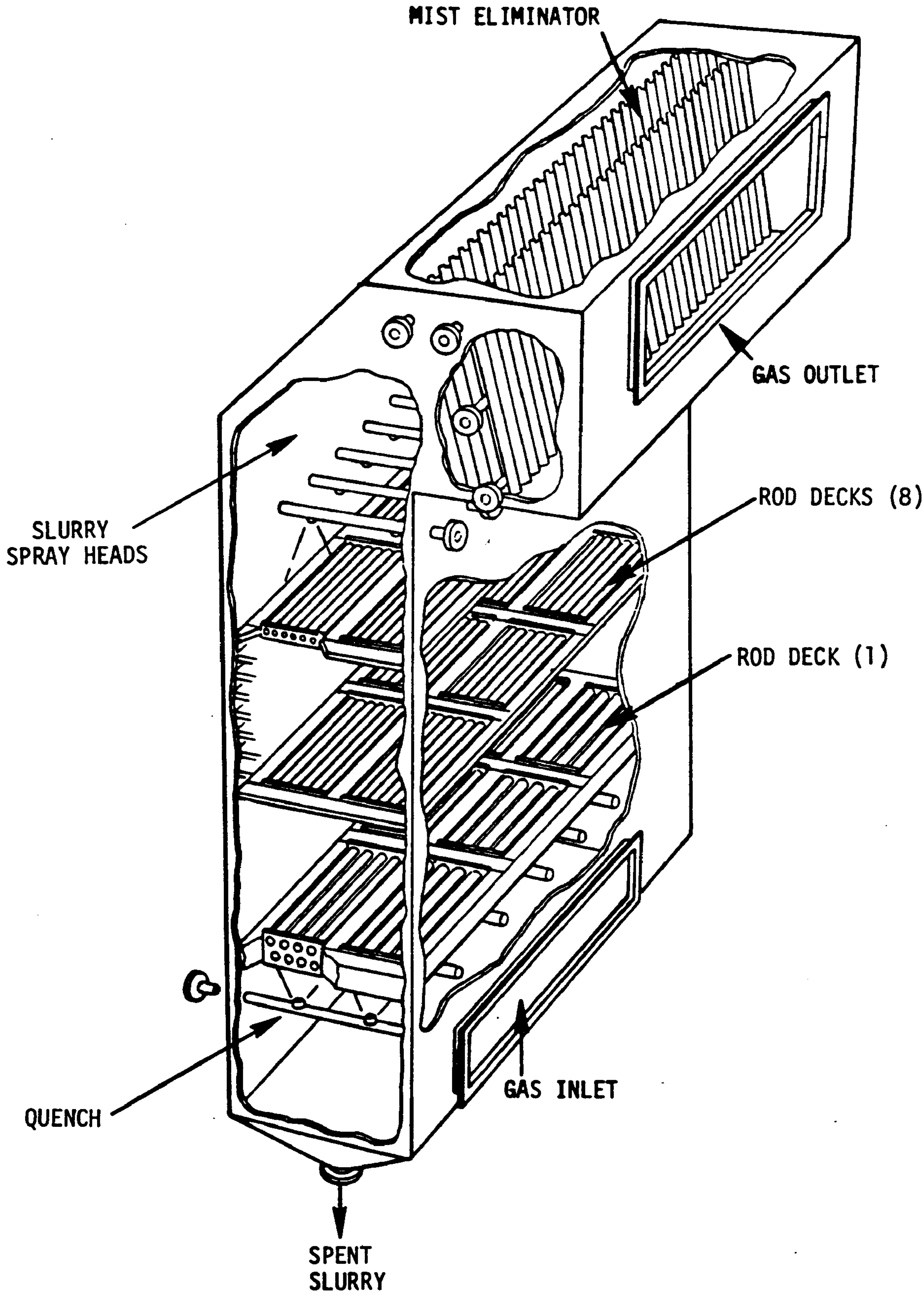


Figure 6. Cutaway view of a Duck Creek 1 FGD scrubber module.

or all of the scrubber modules during outages or emergencies. The major components are the bypass breeching, control damper, bypass breeching damper, induced-draft fan isolation dampers, and scrubber module isolation dampers.

Bypass Breeching--

A breeching section, which can accommodate all or part of the flue gas flow, is provided for FGD gas bypass. It consists of a straight duct run extending from the discharge side of the induced-draft fans to the stack entry point. Flue gas enters and exits the FGD system via a common inlet and discharge duct, which routes gas to and from each of the scrubber modules. The common inlet and discharge ducts exit the bypass breeching downstream of the discharge side of the induced-draft fans and enter upstream of the stack entry point. During partial or full load bypass situations the flue gas can pass directly from the induced-draft fans to the stack for discharge to the atmosphere.

Two important features of the breeching section are the materials of construction and an emergency water spray. The bypass breeching is constructed of Hastelloy G. This material provides superior corrosion resistance under all gas conditions, including the hot/dry environment associated with full bypass, the warm/wet environment associated with partial bypass and partial scrubbing, and the cool/saturated environment associated with full scrubbing. The emergency water spray is situated in the breeching just prior to the stack entry point. The purpose of this system is twofold: (1) to provide emergency cooling in the event of a high temperature excursion [exceeding 175°C (350°F)], which could severly damage the stack liner, and (2) to provide continuous cooling of the gas bypassing the FGD system so that the condition of the gas passing through the stack is nearly constant, thus extending the life of the liner.

Control Damper--

A control damper situated in the common duct downstream of the discharge side of the induced-draft fans regulates gas flow to the stack so that a maximum of 25 percent of the design gas flow of 648 m^3/s (1,415,600 acfm) at 135°C (275°F) enters each scrubber. Any gas flow in excess of the design value goes directly to the stack.

Bypass Breeching Damper--

The bypass breeching is equipped with a single-louver shut-off damper that seals off the breeching, permitting flue gas to enter the FGD system.

Induced-draft Fan Isolation Dampers--

Each of the four induced-draft fans is equipped with double-inlet control dampers and a double-outlet damper so that any one of the fans can be isolated from the flue gas path. The outlet dampers, which are located on the discharge side of the induced-draft fans, are double-louver, seal-air units that operate in parallel. A seal-air fan pressurizes the area between the dampers when they are in the closed position to prevent gas leakage from the pressurized discharge duct back into the fan.

Scrubber Module Isolation Dampers--

Each of the four scrubber modules is also equipped with a set of inlet and outlet dampers, so that any one of the modules can be isolated from the flue gas path. The inlet dampers, which are located in the inlet duct to each scrubber, are double-louver, seal-air units that operate in parallel. A seal-air fan pressurizes the area between the dampers when they are in the closed position and prevents gas leakage into the scrubber during maintenance periods or while the boiler is in service. The outlet dampers, which are located in the outlet duct of each scrubber, are double slide-gate dampers that operate in parallel. Two seal-air fans are provided for each set of outlet dampers. One operates continuously and pressurizes the damper drive mechanisms. The other pressurizes the area between the dampers when both slide gates are in the closed position.

Figure 7 is a simplified diagram of the Duck Creek FGD system duct work and damper arrangement.

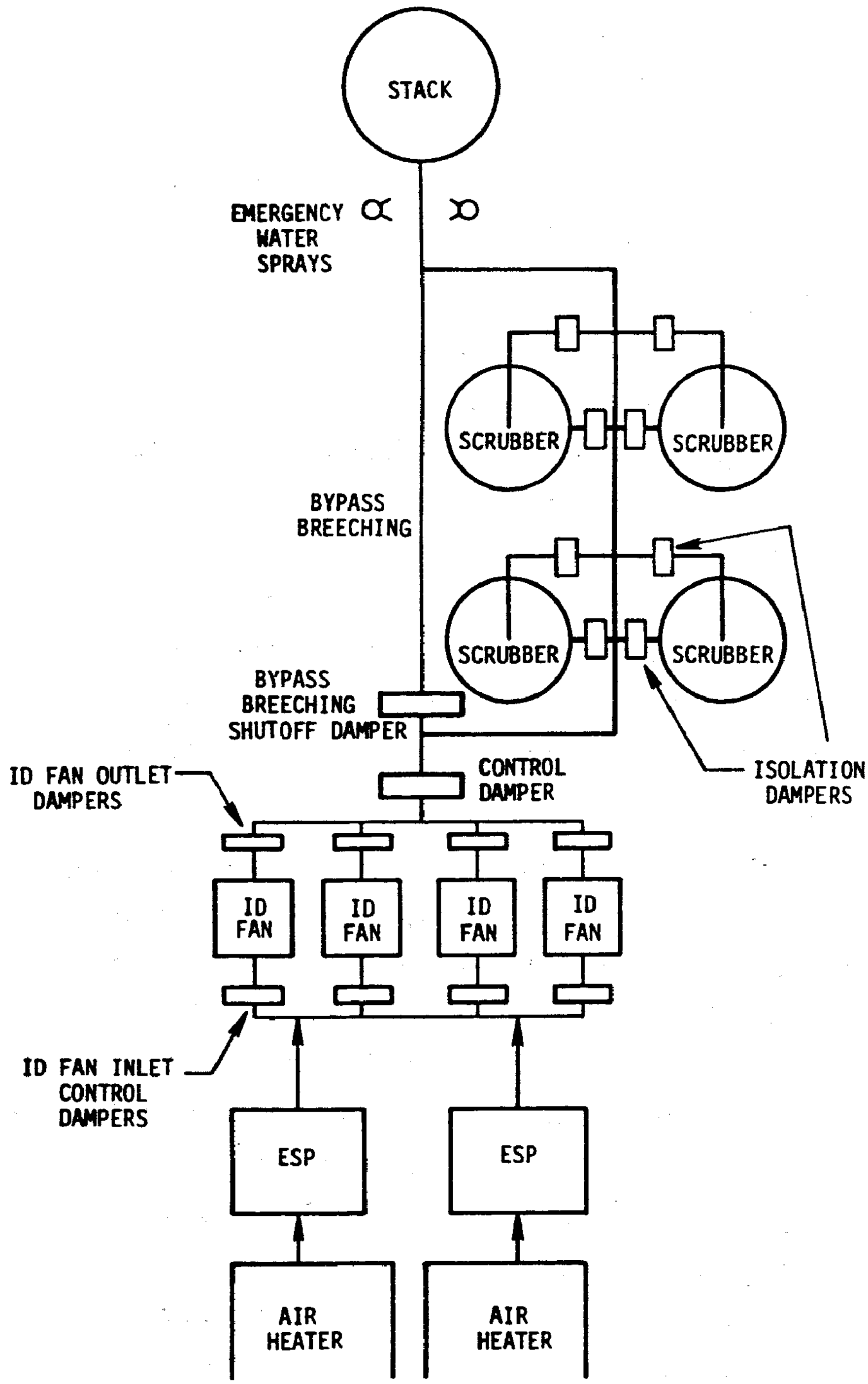


Figure 7. Duck Creek 1 duct work and damper arrangement.

Solids Disposal and Water Return

Spent scrubbing slurry is bled from the scrubber recirculation lines as a 15 percent solids slurry containing reaction products, unreacted limestone, and collected fly ash. The spent slurry is transferred to a waste collection tank, where it is combined with liquid waste streams from plant sumps, and then discharged to an onsite sludge disposal pond. The pond, which is lined with a natural impermeable material, covers approximately 263,000 m^2 (65 acres). Bottom ash and collected fly ash are also stored here. The waste solids present in the spent scrubbing slurry settle out in the pond, and the supernatant is returned to the plant for reuse. Recycled water is used in the recycle tanks to maintain liquid levels and for sluicing the bottom ash and fly ash to the disposal pond. Figure 8 is a simplified diagram of the Duck Creek waste disposal and water return loop.

PROCESS DESIGN

Fuel

The Duck Creek 1 emission control system is designed to remove particulate and sulfur dioxide resulting from the combustion of a high sulfur bituminous Illinois coal from nearby surface mines. Table 6 presents specifications and consumption rates of the performance coal.

Particulate Removal

Primary particulate control is provided by two half-size, cold-side ESP's situated upstream of the FGD system. These Pollution Control-Walther ESP's are new units that were installed as original power plant equipment. Table 7 summarizes the design parameters.

Sulfur Dioxide Removal

Primary sulfur dioxide removal is provided by a four-module limestone FGD system situated downstream of the ESP's. Table 8

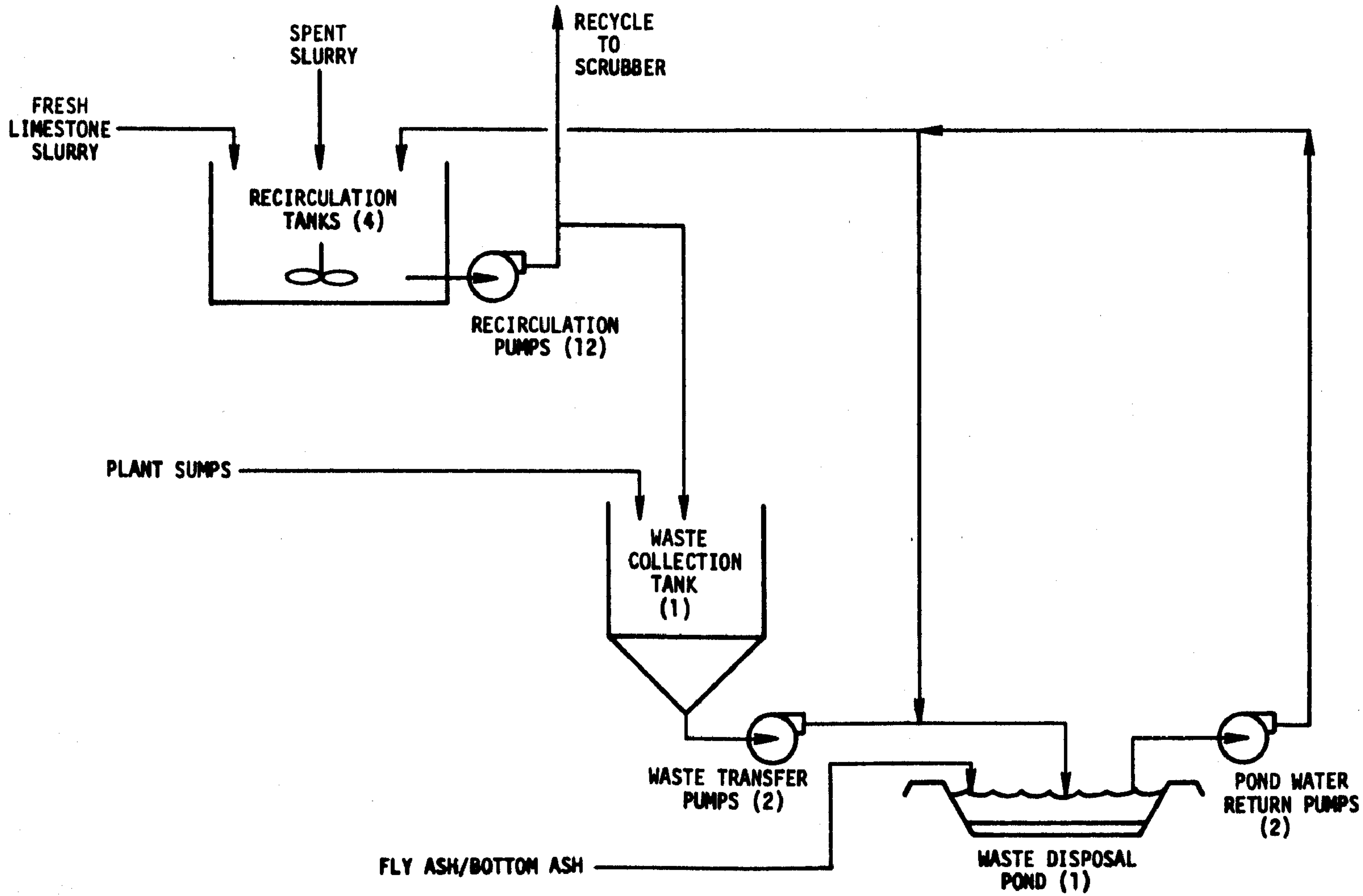


Figure 8. Duck Creek 1 waste disposal and water return loop.

TABLE 6. SPECIFICATIONS AND CONSUMPTION RATES OF DUCK CREEK PERFORMANCE COAL

Fuel	Pulverized coal
Grade	Bituminous
Source	Illinois
Total raw coal (maximum), kg/h (lb/h)	173,839 (383,249)
Sulfur (maximum), kg/h (lb/h)[a]	7,058 (15,560)
Hydrogen (maximum), kg/h (lb/h)[b]	10,430 (22,995)
Ash (maximum), kg/h (lb/h)[c]	31,291 (68,985)
Moisture (maximum), kg/h (lb/h)	39,983 (88,147)
Volatile matter (maximum), kg/h (lb/h)[c]	60,844 (134,137)
Fixed carbon (maximum), kg/h (lb/h)[c]	78,227 (172,462)
Heat input (maximum), GJ/h (10^6 Btu/h)	4,260 (4,040)

[a] Moisture free.
[b] Moisture and ash free.
[c] As received.
[d] Based on a coal heat content of 24,523 kJ/kg 10,543 (Btu/lb).

TABLE 7. DESIGN PARAMETERS OF DUCK CREEK 1 ESP

Number	Two
Arrangement	Parallel
Type	Cold side
Supplier	Pollution Control-Walther
Inlet gas conditions:	
Volume, m^3/s (acfm)	717 (1,520,000)
Temperature, °C (°F)	135 (275)
Weight, kg/h (lb/h)	2,107,000 (4,646,000)
Pressure, kPa (in. H_2O)	4.60 (18.4)
Particulate, g/m^3 (gr/acf)	10.5 (4.57)
Outlet gas conditions:	
Volume, m^3/s (acfm)	717 (1,520,000)
Temperature, °C (°F)	135 (275)
Weight, kg/h (lb/h)	2,024,000 (4,463,100)
Pressure, kPa (in. H_2O)	4.48 (17.9)
Particulate, mg/m^3 (gr/acf)	0.02 (0.009)[a]
Removal efficiency, percent	99.8[b]

[a] Maximum guaranteed particulate emission level.

[b] ESP maximum guaranteed removal efficiency based on a coal sulfur content of 2 percent.

TABLE 8. DESIGN PARAMETERS OF DUCK CREEK 1 FGD SYSTEM[a]

Inlet gas conditions:	
Volume, m^3/s (acfm)	668 (1,415,600)
Temperature, °C (°F)	135 (275)
Weight, kg/h (lb/h)	2,107,000 (4,646,000)
Pressure, kPa (in. H_2O)	2.5 (10)
Sulfur dioxide, kg/h (lb/h)	14,115 (31,120)
Particulate, kg/h (lb/h)	51 (113)
Outlet gas conditions:	
Volume, m^3/s (acfm)	572 (1,211,000)
Temperature, °C (°F)	53 (127)
Weight, kg/h (lb/h)	2,172,000 (4,788,424)
Pressure, kPa (in. H_2O)	0.5 (2)
Sulfur dioxide, kg/h (lb/h)	2,074 (4,572)
Particulate, kg/h (lb/h)	60 (132)
Sulfur dioxide removal efficiency, percent	85.3

[a] Maximum performance coal characteristics of 4 percent sulfur and 18 percent ash.

presents inlet and outlet gas conditions and design removal efficiencies.

Rod-deck Scrubber

The rod-deck scrubber is a proprietary, second-generation design scrubbing vessel developed by Riley Stoker/Environeering and marketed under the name Ventri-Sorber Scrubber. The vertical, multistage scrubber is a countercurrent gas-liquid flow module which contains a series of rod decks arranged vertically on staggered centers within the vessel. The rods in each rod deck are 2.5 cm (1 in.) in diameter and spaced 2.5 cm (1 in.) apart. Table 9 presents design parameters and operating conditions of the scrubber module. Figure 6 presents a cutaway view of the module, showing the overall arrangement as well as the internals.

Mist Eliminator

Each scrubber module has a separate set of mist eliminators arranged in a tilted-vertical position in the horizontal discharge ducts. The mist eliminators are equipped with a freshwater wash system which consists of a common wash-down tank and spray pumps and piping for each mist eliminator. The wash system is capable of delivering 55 liters/s (885 gal/min) of freshwater to each mist eliminator. The water is sprayed on the second mist eliminator, then collected in the wash-down tank and reused on the first mist eliminator. Table 10 presents design parameters and operating conditions of the mist eliminators.

Gas Dampers

The flue gas bypass network is comprised of several bypass dampers, isolation dampers, and seal-air fans which enable the gas to bypass any or all of the scrubber modules and induced-draft fans during forced outages without having to shut down the unit or reduce the load. Table 11 presents design parameters and operating conditions of the dampers.

TABLE 9. DESIGN PARAMETERS AND OPERATING CONDITIONS OF DUCK CREEK 1 SCRUBBERS

Number of modules	4
Type	Rod deck
Configuration	Vertical
Shape	Rectangular, inverted L
Flow pattern	Countercurrent
Dimensions	
Length, m (ft)	12 (40)
Width, m (ft)	1.5 (5)
Height, m (ft)	12 (40)
Number of stages	9
Number of spray heads	12
Arrangement of internals:	
Number of rod decks	9
Geometry	Vertical, staggered off center
Rod diameter (outer), cm (in.)	2.5 (1)
Rod spacing, cm (in.)	2.5 (1)
Materials of construction:	
Shell	Carbon steel
Internals	Hastelloy G
Rods	316L stainless steel
Inlet flue gas volume, m^3/s (acfm)	167 (353,900)
Inlet flue gas temperature, °C (°F)	135 (275)
Flue gas velocity, m/s (ft/s)	3.9 (13)
Pressure drop, kPa (in. H_2O)	2 (8)
Liquid recirculation rate, liters/s (gal/min)	994 (15,750)
Liquid to gas (L/G) ratio, liters/m^3 (gal/10^3 acf)	6.8 (50)[a]
Outlet flue gas volume, m^3/s (acfm)	143 (302,750)
Outlet flue gas temperature, °C (°F)	53 (127)
Maximum slurry feed rate, kg/min (lb/h)	345 (45,600)

[a] Approximate L/G value at saturated gas conditions.

TABLE 10. DESIGN PARAMETERS AND OPERATING CONDITIONS OF DUCK CREEK 1 MIST ELIMINATORS

Number	4
Number per module	1
Type	Chevron
Configuration	Vertical-tilted 35 degrees from vertical plane
Shape	Z-shape, 90-degree bends
Number of stages	2
Number of passes	3
Distance between stages, m (ft)	1.2 (4)
Distance between vanes, cm (in.)	6.4 (2.5)
Materials of construction	Hastelloy G
Wash system:	
Water source	Fresh (2nd stage); spent wash from 2nd stage collected and used for 1st stage
Point of addition/collection	Wash-down tank
Wash direction	1st stage - front and back 2nd stage - front
Frequency	Continuous
Rate	1st stage - 56 liters/s (885 gal/min) 2nd stage - 49 liters/s (775 gal/min)[a]
Pressure	Low

[a] Approximately 850 liters (225 gal) per min of wash water is lost to gas stream as entrained moisture droplets. Each stage contributes half of this water loss. Approximately 2500 liters (660 gal) per minute of spent wash water from both stages is drained from the wash-down tank to each recirculation tank.

TABLE 11. DESIGN PARAMETERS AND OPERATING CONDITIONS OF DUCK CREEK 1 DAMPERS

Description	Number	Type	Manufacturer	Modulation	Seal air		Service conditions, °C(°F)/min	Torque, mPa (psi)	Comments
					Flow, m^3/s (acfm)	Pressure, kPa (in. H_2O)			
Induced-draft fan inlet	8		Buffalo Forge		None				Inlet-control dampers
Induced-draft fan outlet	4	Double-louver	American Warming and Ventilating	Open/closed	1.95 (4,150)	5.5 (22.0)	370/30 (700)	113(16,500)[a]	Isolation dampers
Bypass breeching inlet	1	Single-louver	American Warming and Ventilating	Open/closed	None		232/30 (450)	276(40,000)	Inlet-control dampers
Scrubber module inlet	4	Double-louver	American Warming and Ventilating	Open/closed	1.95 (4,150)	5.5 (22.0)	232/30 (450)	83.6(12,125)[a]	Isolation dampers
Scrubber module outlet	8	Double-plate slide-gate	Environmental Elements	Open/closed	0.57 (1200)	2.5 (10.0)	232/30 (450)		Isolation dampers

[a] Per side.

Induced-draft Fans

Four centrifugal induced-draft fans are connected in parallel to a common duct with internal baffling promote even gas flow distribution to the scrubbers and/or bypass breeching. These fans are designed to operate in tandem with the boiler forced-draft fans to overcome draft loss in the boiler side and emission-control side. Each fan is equipped with a water-cooled oil-lubrication system, complete with pumps and coolers. Table 12 presents the design parameters and operating conditions of the fans.

Pumps

The FGD system is equipped with 34 pumps covering the liquid circuit battery limits from limestone preparation to waste solids disposal. Table 13 presents design parameters and operating conditions of the pumps.

Tanks

The liquid circuit of the FGD system is equipped with 11 major tanks for storage, transfer, recirculation and collection of slurry, and addition of makeup water. Table 14 presents design parameters and operating conditions of the tanks.

Wet Stack

The FGD system has no stack gas reheat system. It is designed so that the scrubbed gas stream exits the system at approximately 53°C (127°F). The bypass duct and stack also handle the warm and hot flue gas streams associated with partial and total FGD bypass. The wide variety of operating conditions has necessitated the incorporation of a number of design features, which are summarized as follows:

- The bypass breeching and discharge ducts are constructed of Hastelloy G, an exotic, corrosion-resistant alloy.

TABLE 12. DESIGN PARAMETERS AND OPERATING CONDITIONS OF DUCK CREEK 1 INDUCED-DRAFT FANS

Number	4
Manufacturer	Buffalo Forge
Arrangement	Parallel
Service	Dry
Specifications:	
Type	Centrifugal, double width, double inlet, radial tip
Rating, kW (hp), and rpm	2,960 (4,000), 900
Lube system	Water-cooled, circulating oil
Bearings	Self-aligning sleeve type
Rotation	2 CW[a], 2 CCW[b]
Performance:	
Gas capacity, m^3/s (ft^3/min)	205 (435,000)
Gas temperature, °C (°F)	149 (300)
Gas density, kg/m^3 (lb/ft^3)	0.785 (0.049)
Pressure drop, kPa (in. H_2O)	9.5 (38.0)
Materials of construction	Carbon steel

[a] CW = clockwise.
[b] CCW = counter clockwise.

TABLE 13. DESIGN PARAMETERS AND OPERATING CONDITIONS OF DUCK CREEK 1 PUMPS

Number	Service	Manufacturer	Type	Materials of construction	Performance: Motor, kW (hp)	Performance: Capacity, liters/s (gal/min)	Performance: Speed, rpm	Performance: Solids, percent	Operation
2	Mill sump	Galigher	Centrifugal slurry	Rubber-lined		50(800)	1800	55	1 operational, 1 spare
4	Slurry transfer and return	Worthington	Centrifugal slurry	Rubber-lined		45(705)	1800	40-50	1 operational, 3 spare
12	Slurry re-circulation	Worthington	Centrifugal slurry	Rubber-lined	215(290)	497(7875)	770	15	8 operational, 4 spare
12	Mist eliminator spray	Worthington	Centrifugal	Rubber-lined	26(35)	66(1050)	1800	0	8 operational, 4 spare
2	Waste collection underflow	Barret	Centrifugal slurry	Rubber-lined	89(120)	100(1600)	985	15	1 operational, 1 spare
2	Pond water return	Worthington	Centrifugal	Rubber-lined		50(800)	1800	0	1 operational, 1 spare

TABLE 14. DESIGN PARAMETERS AND OPERATING CONDITIONS OF DUCK CREEK 1 TANKS

Service description	Number	Dimensions, m (ft)	Capacity, liters (gal)	Retention time, min	Agitator	Materials of construction	Comments
Slurry recirculation	4	11 dia. x 6.7 (37 dia. x 22)	606,000 (160,000)	10	Yes	Rubber-lined carbon steel	1 per scrubber
Slurry storage	1	7.9 dia. x 6.1 (26 dia. x 20)	303,000 (80,000)	100	Yes	Rubber-lined carbon steel	Common
Mist eliminator wash down	4	1.5 dia. x 3.0 (5 dia. x 10)	11,400 (3,000)	3.5	No	Rubber-lined carbon steel	1 per scrubber
Mill slurry	2				Yes	Concrete	1 operational, 1 spare

- Emergency water sprays are located in the discharge duct just prior to the stack entry point. The water sprays provide emergency cooling for stack liner protection in the event of a high temperature excursion. The water sprays also provide continuous cooling of the gas bypassing the FGD system so that a constant gas environment is created within the stack, thereby extending stack liner life.

- The 152-m (500-ft) stack is a reinforced-concrete shell. Its Cor-Ten flue is coated with a sprayed-on flake-glass liner (Ceilcote 151) for protection from acid corrosion attack. A venturi throat placed approximately two-thirds of the way up the stack gives the gas a mechanical boost before it is discharged to the atmosphere. This boost causes a difference in the velocity of the gas and the entrained droplets, allowing the latter to fall out of the gas stream and be collected in four hoppers situated at the base of the stack.

Limestone Storage and Preparation

Limestone arriving at the plant is either delivered to a dead storage or live storage area or is transferred directly to the limestone grinder building. The dead storage area holds 90 days supply and the live storage area, 3 days. Limestone delivered to the grinder building is stored in a feed bin having a 24-h storage capacity.

The limestone delivered to the storage bin is 1.9 cm (3/4 in.) and must be ground to a particle size of 90 percent minus 200 mesh. Grinding takes place at 10 kg/s (40 tons/h) in one of two (one operational, one spare) wet ball mills to which the stone is supplied by a weigh feeder. Fresh makeup water is fed to the ball mill at 14 liters/s (220 gal/min) under maximum conditions (100% boiler load, 4% sulfur coal). The milled limestone is discharged to a slurry tank for collection, then pumped to a slurry storage tank via a classifier that insures a 90 percent minus 200 mesh product. The effluent from the mill system, which is a 40 percent solids slurry, is retained in the slurry storage tank for 100 minutes before it is added to the liquid scrubbing circuit via the scrubber recirculation tanks.

Tables 15 and 16 present design parameters and operating conditions of the Duck Creek limestone storage and preparation operations.

TABLE 15. DESIGN PARAMETERS AND OPERATING CONDITIONS OF DUCK CREEK 1 LIMESTONE STORAGE FACILITIES

Description	Number	Capacity, Gg (tons)	Storage, days
Dead storage	1	39.2 (86,400)	90
Live storage	1	1.30 (2,880)	3
Feed bin	1	0.4 (960)	1

Waste Solids Disposal and Pond-water Return

The spent scrubbing slurry from the recirculation lines of each module is discharged to a waste collection tank where it is combined with liquid waste streams from plant sumps and discharged to an onsite sludge disposal pond. The waste collection tank is situated in a sludge building located approximately half way between the plant and pond. The sludge disposal pond, which also accommodates bottom ash and fly ash disposal, has a 3- to 5-yr service life. It is lined with a natural impermeable material to prevent contamination of water streams. The inlet waste stream to the disposal pond consists of a 15 percent solids slurry containing reaction products, fly ash, bottom ash, and unreacted limestone. The waste solids settle out in the pond, and supernatant is returned to the recirculation tanks to maintain liquid balance in the FGD system. Table 17 presents design parameters and operating conditions of the waste disposal system.

PROCESS CHEMISTRY: PRINCIPAL REACTIONS

The chemical reactions involved in the Duck Creek wet limestone scrubbing process are highly complex. Although details are beyond the scope of this discussion, the principal chemical mechanisms are described below.

TABLE 16. DESIGN PARAMETERS AND OPERATING CONDITIONS OF DUCK CREEK 1 LIMESTONE PREPARATION FACILITY

Weigh feeder:	
Number	One
Manufacturer	Merrick
Capacity	45 Mg (50 tons)/h of 1.3 cm (0.5 in.) stone at 1.5 to 1.8 Mg/m^3 (95 to 110 lb/ft^3), 65°C (150°F), and 15.5 m/min (50.95 ft/min)
Ball mill:	
Number	Two (one operational, one spare)
Manufacturer	Kennedy Van Saun
Motor drive	Falk/General Electric
Mill speed, rpm	18.36
Bearings	Oil lubricated
Ball charge, Mg (lb)	67 (148,000)
Capacity, Mg/h (tons/h)	36 (40)
Slurry solids, percent	65
Classifier:	
Number	One
Manufacturer	Krebs
Dimensions, m (ft)	0.3 x 1.3 (1.0 x 4.2)
Lining	Rubber
Rating	90 percent minus 200 mesh
Overflow, Mg/h (tons/h)	36 (40)
Underflow, Mg/h (tons/h)	72 (80)
Inlet flow, liters/s (gal/min)	17.7 (281)
ΔP, kPa (psig)	245 (20.5)
Slurry solids, percent	40

TABLE 17. DESIGN PARAMETERS AND OPERATING CONDITIONS OF DUCK CREEK 1 WASTE DISPOSAL SYSTEM

Method	Ponding
Number	One
Type	Clay-lined settling pond
Location	Plant site
Area dimensions, m^2 (acre)	263,000 (65)
Distance from plant, km (mi)	0.8 (0.5)
Transportation mode	Pipeline
Pond permeability, cm/s (in./s)	10^{-8} (10^{-10})
Annual storage capacity:	
Ash, Gg (tons)	218 (240,000)
Reaction products, Gg (tons)	816 (900,000)
Volume, m^3 (acre-feet)	328,700 (266.5)
Service life, yr	3 to 5
Pond water return rate, liters/s (gal/min)	46.6 (738)
Pond water return points	Recirculation tanks

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

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

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

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

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

This species, like sulfur dioxide, is an acidic anhydride that reacts readily to form an acid in the presence of water.

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

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

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 oxidation of sulfur dioxide to form sulfur trioxide, oxidation of sulfite ion by dissolved oxygen (DO) in the scrubbing slurry is limited.

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

The limestone absorbent, which is 95 percent calcium carbonate by weight, is introduced into the scrubbing system as a slurry with water. At Duck Creek limestone is added to the FGD system at a stoichiometric rate of 1.5 moles per mole of sulfur dioxide removed. Limestone is largely insoluble in water, and solubility increases only slightly as the temperature increases. In the scrubbing system, the slurry dissolves and ionizes into an acidic aqueous medium, yielding the ionic products of calcium, carbonate, bicarbonate, and hydrogen.

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

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

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

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

The chemical absorption of sulfur dioxide occurs in the scrubber modules and is completed in the external recirculation tanks.

$$Ca^{++} + SO_3^{=} \rightleftharpoons CaSO_3$$

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

The calcium sulfite and calcium sulfate reaction products, along with the collected fly ash and unreacted limestone, are transferred to the disposal pond. After the sulfur dioxide reaction products precipitate as hydrated calcium salts and settle out with the other waste solids, the supernatant is returned to the recirculation tanks for reuse.

$$CaSO_3 + 1/2H_2O \rightleftharpoons CaSO_3 \cdot 1/2H_2O$$

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

PROCESS CONTROL

The Duck Creek FGD system operations are monitored and controlled from a control panel situated in a cubicle in the limestone grinder building. The control cubicle contains the analog and digital control elements for automatic monitoring and control of the FGD process inlet and outlet streams. The principal concerns of this control network are flue gas flow, reagent feed, and slurry solids.

Flue Gas Flow

Gas flow through the scrubber modules is monitored and controlled to prevent overloading and loss of chemical control. Control is accomplished by maintaining a constant pressure drop across the system. Each scrubber module has differential pressure sensors in the inlet and outlet gas ducts. These sensors relay signals through a differential pressure transmitter to a controller in the boiler control room. The controller maintains a constant pressure drop of 2 kPa (8 in. H_2O) across each module by adjusting the bypass damper in the bypass breeching through modulation of an electric drive. This single-louver shutoff damper can be modulated to any position between fully open and fully closed to maintain proper gas flow distribution and constant pressure drop.

Another important aspect of this control network is the operation of isolation dampers. Each scrubber module is equipped with one double-louver, seal-air damper on the inlet and two slide-gate, seal-air dampers on the outlet. Each damper is powered by an electric drive and controlled automatically or manually from the control cubicle. The automatic control network is actuated by differential pressure and liquid flow sensors in the mist eliminator and scrubber recirculation liquid loops. When below normal values are registered in either of these loops, the dampers are automatically closed and seal-air fans are activated to insure complete seal-off.* The dampers reopen when readings return to normal in both loops. Each damper can be operated manually from the control cubicle during periods of reduced load or outages. During manual operation the dampers can be moved to a closed or intermediate position and reopened only when readings return to normal.

Reagent Feed

Fresh limestone slurry is continuously added to the FGD scrubber recirculation tanks to compensate for reagent consumed

* One set of seal-air fans operates continuously, pressurizing the damper drive mechanisms for the outlet slide-gate dampers of each scrubber module.

in scrubbing operations, thereby maintaining sulfur dioxide removal efficiency and chemical integrity. The flow of fresh limestone slurry into the scrubbing circuit is controlled in an automatic feed-forward/feedback manner. Primary control is provided by the feed-forward network, which utilizes the inlet gas stream's sulfur dioxide concentration and flow rate. Fine control or "trim" is provided by the feedback network, which utilizes slurry pH and inlet slurry flow rate. The following paragraphs summarize the specifics of these control networks.

The flow of sulfur dioxide and boiler gas is measured by sulfur dioxide gas monitors and boiler load signals originating in the boiler control room. Sulfur dioxide is measured by six continuous gas monitors situated at the system inlet duct, at the system outlet duct, and at each scrubber module outlet. The signals from all these monitors are recorded and transferred to an analyzer, which transmits a signal to a computer, indicating the inlet sulfur dioxide concentration. The boiler load signal is also transmitted to the computer, indicating the proportional amount of limestone slurry needed for sulfur dioxide removal. This output signal enters another computer, which produces four separate signals that then enter a flow controller. The flow controller is connected to an actuator that regulates the position of a butterfly control valve. Each of these signals can be biased in relation to the individual scrubber module gas flow.

The flow controller also receives two input signals from pH monitors situated in the recirculation tanks and from another computer, which transmits an output signal proportional to slurry flow rate into the recirculation tanks. The input signals for this computer are provided by a magnetic flow meter and density meter located in the storage tank slurry loop and the storage tank itself.

These three signals (inlet gas flow/sulfur dioxide concentration, slurry pH, and slurry flow) provide the input to the flow controller that actuates the flow control valves located in each of the four tap lines, which draw off fresh slurry from the storage tank return loop. The slurry pH control point is set at 5.5 to 6.0.

Slurry Solids

The solids content of the slurry in the scrubbing circuit is controlled at the 15 percent level by monitoring the liquid level of the recirculation tank, the slurry density, the fresh slurry flow rate, and the spent slurry flow rate. A recirculation tank level controller and a slurry discharge controller are used in conjunction with a computer to operate a slurry discharge flow control valve for each scrubber. Input signals to the computer and controllers are sent from differential pressure level transmitters and density meters in the recirculation tanks and from flow meters in the slurry feed and discharge lines. Using these signals, the controllers maintain a set ratio between incoming and outgoing slurry to the recirculation tanks and the overflow spent wash water from the mist eliminator wash-down tanks to maintain a 15 percent solids level in the slurry scrubbing circuit.

SECTION 4

FGD SYSTEM PERFORMANCE

BACKGROUND INFORMATION

Originally CILCo intended to install one scrubber for the control of sulfur dioxide emissions at Duck Creek 1, and to evaluate its effectiveness on high sulfur coal before proceeding with the design, installation, and operation of the remaining scrubber modules. It was believed that such a modular approach would produce sufficient operating data on the scrubbing of flue gas produced by high sulfur coal so that any drastic design changes might be made without large capital investments or unit load reductions.

In 1974 the Illinois EPA approved the modular approach for the Duck Creek 1 FGD system. Permission was granted for CILCo to build and operate only one 100-MW equivalent scrubber module initially, and to build the remaining three modules after this module had been tested sufficiently. As a result of this ruling, CILCo awarded a contract to Riley Stoker/Environeering (in November 1974) for the design and construction of an FGD system that included only one scrubber module to treat 25 percent of the total boiler flue gas flow.

In October 1975, the U.S. EPA served a notice of violation, requiring the entire plant to comply with New Source Performance Standards governing sulfur dioxide emissions. The utility obtained a consent decree and elected to move up the expected completion date of the remaining scrubber modules to August 1, 1978, and on August 26, 1976, awarded Riley Stoker/Environeering a contract to supply these modules. The utility was also granted a variance to fire high sulfur coal in the boiler from July 1, 1976, to April 1, 1977, for test purposes. The unit could be operated at full load during this period with both ESP's and one scrubber module in the gas path.

The first scrubber module (D-scrubber) was completed in June 1976, placed in service on July 1, 1976, and operated intermittently throughout the fall and winter and for approximately 1 month in the spring of 1977. The purpose of this operation was to verify process chemistry and design. During this brief period of service, several problems became apparent, making subsequent design modifications necessary. The modifications were made and the remaining modules were installed between April 1977 and July 1978. During this time the utility burned low sulfur coal in order to meet the sulfur dioxide emission standard of 516 ng/J (1.2 $lb/10^6$ Btu). Initial startup of the entire FGD system commenced on July 23, 1978.

Because the Duck Creek 1 FGD system has only recently attained commercial operating status, operating data are limited. However, the data obtained during the D-scrubber test (removal efficiencies, problems, solutions, and necessary design modifications) are discussed in the remainder of this section.

OPERATING HISTORY AND PERFORMANCE

Duck Creek 1 commenced commercial operation on June 1, 1976, and the D-scrubber module was initially placed in the flue gas path on July 1, 1976. The limited operation during the balance of July and August was due primarily to construction deficiencies, such as bad welds, faulty pipe hangers, and slurry leaks in the scrubber. The D-scrubber was taken out of the gas path to resolve these problems and put back in on September 9. It operated (intermittently) for approximately 360 hours during the balance of the month, 385 hours in October, and 24 hours in November. During these periods a number of major operating problems were encountered, including massive mist eliminator scale, spray nozzle and pipe plugging, and materials failure.

The module remained out of service from December through February because of a scheduled 3-month boiler/turbine overhaul. During this outage a number of modifications were made to the scrubber in order to correct the major operating problems encountered. The unit was placed back in service in mid-March, and the D-scrubber operated almost continuously for 350 hours during the balance of the month. During April and May, testing was to concentrate on operating the automatic control loops; however, the testing was terminated prematurely because of installation difficulties, and the D-scrubber was taken out of service. The unit remained in service with the boiler firing low sulfur Colorado coal. The ESP's also remained in service, and with the aid of sulfur trioxide gas injection, removed particulate from the flue gas generated by the burning of low sulfur coal. The D-scrubber was placed back in the flue gas path on July 23, 1978, along with the other scrubber modules. Table 18 summarizes the performance of the D-scrubber during the July 1976 to April 1977 test period.

PROBLEMS AND SOLUTIONS

The interim testing of the D-scrubber module revealed several chemical, mechanical, and design-related problems and prompted a number of modifications to the system. All of the problems were not directly related to design deficiencies however; some were caused by operating the scrubber before it was completely installed. These items are discussed briefly in the paragraphs that follow.

Chemical Problems

Many of the chemical problems that beset the D-scrubber module and ancillary equipment were caused or aggravated by an incomplete instrumentation/control network. The sophisticated automatic control system could not be put in service during this early stage of operation.

TABLE 18. DUCK CREEK 1 D-SCRUBBER MODULE PERFORMANCE HISTORY

Period	Module Service	Comments
Jul. 1976	8 h	Initial operation of the D-scrubber module for shakedown and debugging purposes occurred during the month. Limited service time resulted from bad welds, faulty pipe hangers, and slurry leaks in the module.
Aug. 1976	18 h	Limited operations continued because of continued startup and construction problems. The module was taken out of the gas path to concentrate on resolving these problems.
Sept. 1976	360 h	Module restart occurred on September 9. Operation continued throughout the remainder of the month on an intermittent basis. Major problems included pipe breaking, pump liner failures, plugging and sealing of mist eliminators, and some boiler-related problems. The module remained in service for approximately 15 days of noncontinuous operation.
Oct. 1976	385 h	Total operation time during the month amounted to approximately 16 days (noncontinuous). The major problem was the continuation of massive scale development on the mist eliminators, resulting in plugging of the piping and nozzles to the components spray system.
Nov. 1976	24 h	Sporadic operation resulted from continued scaling problems in the mist eliminator section. Riley and CILCo initiated modifications to the design of the module. Specifically, a rod deck was changed in the absorber, pressure drop across the absorber was increased, piping and pump liner materials were modified/replaced, and a freshwater wash system was installed for the mist eliminator.
Dec. 1976		The module remained out of service the entire month. During this time, the boiler fired low sulfur (0.6%) Kentucky coal.
Jan. 1977 Feb. 1977		Duck Creek 1 was down throughout the entire period for turbine/boiler overhaul. During the outage, a number of modifications were made to the scrubber.
Mar. 1977	350 h	Duck Creek 1 returned to service in mid-March. The D-scrubber was placed in service to test the following modifications made during the preceding outage: ° The mist eliminator spray wash system piping was changed from PVC to FRP materials, and another spray header was added. ° The slurry circulation system was revamped. ° The original natural rubber liners were replaced with neoprene liners. Flush/drain systems have been included to minimize solids build up. ° Piping valves were moved closer to the recycle tank. ° Slurry storage tanks were equipped with flush/drain systems. ° Additional mixers were added for greater agitation to promote process chemistry. Except for a few minor boiler outages, the module remained in service on a continual basis during the last part of March.
Apr. 1977- Jun. 1978		The firing of Colorado low sulfur coal commenced on April 1 and continued until July 1978.
Jul. 1978		Operation of the FGD system with all four scrubber modules in the flue gas path commenced on July 23, 1978.

Primary difficulties involved frequent scaling and plugging of the mist eliminators. Although these problems were attributed primarily to the lack of automatic controls, the wash system was modified to provide more efficient washing. Specifically, the polyvinyl chloride materials used in the wash water piping that feeds water from the wash-down tank to the spray nozzles for each mist eliminator stage were replaced with fiberglass-reinforced plastic. Also, an additional spray header was added to the wash system to provide more thorough rinsing.

Another chemical problem was the widespread corrosion of the Ceilcote 151 flake-glass liner that was sprayed on the Cor-Ten steel stack flue to a thickness of 0.5 mm (20 mils). Inspection of the liner following the D-scrubber test program revealed blistering and acid corrosion as well as subsequent widespread corrosion of the flue. The major factor contributing to this problem seemed to be the intermittent and partial scrubbing load. This caused the gas conditions to vary widely when passing through the stack, resulting in premature failure of the liner because operating conditions exceeded the design conditions specified for the materials. Two other factors may have contributed to liner failure: the liner material itself (it is no longer offered by the supplier for stack lining applications) and the absence of a stack gas reheat system.

The utility has since repaired areas where cracked and peeled liner exposed bare metal surface, but information on the success of these repairs is not available. Other U.S. utility FGD systems using this wet stack approach have met with the same fate--widespread corrosion of liner, flue, and/or stack, which ultimately required extended outages for repair and/or modification.

Mechanical Problems

Many of the mechanical problems encountered involved premature pump lining failures and damper leakage. Originally, all the slurry recirculation and transfer pumps were lined with natural rubber, and pump cavitation, which occurred frequently, caused the linings to be stripped from the casings. To rectify this, CILCo replaced the natural rubber linings in the slurry recirculation pumps with neoprene linings and the linings in the remaining slurry pumps with reinforced natural rubber.

The utility also equipped all the slurry pumps with a flush-out system. Because the circulating fluid is a slurry (15% solids in the recirculation and discharge lines and 40 to 55% in the transfer lines), solids settle out when flow is stopped. If they settle out in the pump, the pump impeller and lining can be damaged on startup. Therefore, a flush system was installed to purge the pump with freshwater whenever the system is not in service.

Design-related Problems

Several design deficiencies were observed either to have caused or aggravated the chemical and mechanical problems just discussed. These deficiencies are summarized below.

- The ceramic spray nozzles in the scrubber spray heads were originally spinner-vane type. Repeated plugging of these nozzles prompted replacement with orifices in the flow lines (open-pipe arrangement) and splash plates on the top rod deck. The flow orifices reduced the liquid stream from 10 to 5 cm (2 to 4 in.), and the splash plates reduced the potential for erosion of the top rod deck and helped to achieve proper liquid distribution.

- Much of the mist eliminator fouling was attributed to an unexpectedly high carryover of slurry solids in the gas stream. These solids were eventually deposited on the mist eliminators, causing fouling, increased pressure drops across the mist eliminators, and inefficiency of mist eliminator operation. Eventually the scrubber module had to be shut down to clean the mist eliminators. This problem was corrected by increasing the pressure drop across the scrubber by modifying the rod decks. This modification reduced the entrainment of slurry solids in the gas stream and reduced fouling in the mist eliminator.

- In addition to the slurry pumps, freshwater flush and drain systems were added to all the slurry storage tanks, recirculation tanks, and pipe lines to purge them of solids that settle out during periods of inactivity.

- Erosion of piping valves in the scrubber recirculation lines was eliminated by moving the valves closer to the recirculation tanks. Freshwater flush and drain systems have also helped to extend valve life.

- An improper gas velocity profile in the scrubber contributed to some of the problems. Riley Stoker/ Environeering is now attempting to determine the actual profile and necessary corrective action.

- Additional agitation was added to all the slurry tanks to maintain solids suspension in the slurry circuit, minimize solids settling, and promote reaction chemistry.

REMOVAL EFFICIENCY

Because the FGD system has attained its commercial operating status so recently, sulfur dioxide removal efficiencies for full-scale operations are not available; however, sulfur dioxide removal efficiency was measured on the D-scrubber module during the interim test. The results (summarized in Table 19) indicate that the removal efficiency was 91.6 percent, which exceeds the design maximum guarantee value of 85.3 percent.* This measurement was taken for sulfur dioxide inlet concentrations of 3000 ppm.

TABLE 19. RESULTS OF THE D-SCRUBBER MODULE TEST

Gas capacity, m^3/s (acfm)	140 (300,000)
Sulfur dioxide inlet concentration, ppm	3000
Pressure drop, kPa (in. H_2O)	2.2 (8.8)
Liquid/gas ratio, liters/m^3 (gal/10^3 acf)	6.8 (50)
Sulfur dioxide outlet concentration, ppm	252
Sulfur dioxide removal efficiency, percent	91.6

* The efficiency guarantee applied to 4 percent sulfur coal.

Particulate removal efficiency measurements taken during the D-scrubber test program also proved interesting in that the scrubber was apparently removing as much as 70 percent of the inlet particulate matter after it had passed through the upstream ESP's even though scrubbers are not designed to provide any additional particulate removal capability beyond that of the emission control system.* The utility and system supplier indicate that this serendipitous phenomenon may be attributed to the ionization and/or agglomeration of the small particles provided by passage through the upstream ESP's, which would greatly enhance collection of these particles in the downsteam scrubber.

SYSTEM ECONOMICS

The total capital cost of the FGD system reported by CILCo is $37,540,000. This includes $33,740,000 for the entire system and all ancillary equipment and $3,800,000 for the sludge disposal pond. Based on a unit gross generating capacity of 416 MW, this amounts to $90.2/kW. Actual annual cost figures for the FGD system are not available because of limited operation to date. However, based on the limited operation of one module, the utility estimates that the total annual cost of the flue gas desulfurization system is $13,921,000. This includes $7,539,000 for variable charges and $6,382,000 for fixed charges. Based on a net unit rating of 400 MW and a capacity factor of 65 percent, this would amount to 6.11 mills/kWh in total annual cost.

---

* The FGD system is guaranteed not to add any particulate loading to the discharge gas stream as measured at the outlet of the ESP's.

APPENDIX A

PLANT SURVEY FORM

A. Company and Plant Information

1. Company name: Central Illinois Light Company
2. Main office: 300 Liberty Street, Peoria, Illinois
3. Plant name: Duck Creek
4. Plant location: Canton, Illinois
5. Responsible officer:
6. Plant manager:
7. Plant contact: Larry Haynes
8. Position: Manager, Environmental Affairs
9. Telephone number: (309)/672-5221
10. Date information gathered: April 1977

Participants in meeting	Affiliation
L. Haynes	Central Illinois Light Company
B. Laseke	PEDCo Environmental, Inc.
J. Tuttle	PEDCo Environmental, Inc.

B. Plant and Site Data

1. UTM coordinates: ______________________

____

2. Sea Level elevation: ______________________

____

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

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

5. General description of plant environs: The plant site occupies unreclaimed strip-mined land situated in a flat, rural area.

6. Coal shipment mode(s): Coal is delivered to the plant site primarily by rail. Provisions have been made to accommodate truck shipments because of the capability for barge unloading on the Illinois River.

C. FGD Vendor/Designer Background

1. Process: Limestone

2. Developer/licensor: Riley Stoker/Environeering

3. Address: P.O. Box 547, Wooster, Massachusetts, 01613

____

4. Company offering process:

Company: Riley Stoker/Environeering

Address: P.O. Box 547, Wooster, Massachusetts, 01613

Location: ______

Company contact: Tom Robinson

Position: Design Engineer

Telephone number: ______

5. Architectural/engineer:

Company: Gilbert/Commonwealth

Address: ______

Location: Jackson, Michigan

Company contact: H. W. Sauer

Position: Project Manager

Telephone number: ______

D. Boiler Data

1. Boiler: Duck Creek 1
2. Boiler manufacturer: Riley Stoker
3. Boiler service (base, intermediate, cycling, peak):

   Base

4. Year placed in service: 1976
5. Total hours operation (date):: 12,000 (approximate to 10/1/78)
6. Remaining life of unit: 30-year life span
7. Boiler type: Pulverized-coal, balanced-draft, front-fired
8. Served by stack no.: One
9. Stack height: 152 m (500 ft)
10. Stack top inner diameter: ______
11. Unit ratings (MW):

    Gross unit rating: 416 MW

    Net unit rating without FGD: 410 MW

Net unit rating with FGD: 400 MW

Name plate rating: 416 MW

12. Unit heat rate:

Heat rate without FGD: 10,130 kJ net/kWh (9600 Btu/net kWh)

Heat rate with FGD: 10,380 kJ/net kWh (9840 Btu/net kWh)

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

14. Fuel type: Coal

15. Flue gas flow rate: 688 m^3/s (1,415,600 acfm)

Maximum: 688 m^3/s (1,415,600 acfm)

Temperature: 135°C (275°F)

16. Total excess air:

17. Boiler efficiency:

E. Coal Data

1. Coal supplier(s):

Name(s): United Freeman

Location(s): Mines are situated close to plant site in Fulton County near Canton, Illinois.

Mine location(s): Canton, Illinois

County, State: Fulton, Illinois

Seam:

2. Gross heating value: 25,523 kJ/kg (10,543 Btu/lb)

3. Ash (dry basis): 9.12%

4. Moisture: 18.0%

5. Sulfur (dry basis): 3.3%

6. Chloride: 0.03%

7. Ash composition (See Table A1) - Not available.

Table A1

Constituent	Percent weight
Silica, SiO_2	
Alumina, Al_2O_3	
Titania, TiO_2	
Ferric oxide, Fe_2O_3	
Calcium oxide, CaO	
Magnesium oxide, MgO	Not available
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: Federal NSPS
   b) Future requirement: ____
      Regulation and section: ____
2. Applicable SO_2 emission regulation
   a) Current requirement: 516 ng/J (1.2 lb/10^6 Btu)
      Regulation and section No.: Federal NSPS
   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 (95% minimum)

   Function: Absorbent

   Source/manufacturer: Columbia Quarry Company

   Quantity employed: 152 Gg/yr (168,000 tons/yr)

   Point of addition: Scrubber recirculation tanks

2. Trade name: Carbide lime

   Principal ingredient: Calcium hydroxide

   Function: Emergency pH control additive

   Source/manufacturer: AIRCo

   Quantity employed: Emergency pile maintained at plant

   Point of addition: Scrubber recirculation tanks

3. Trade name: Not applicable

   Principal ingredient: ___

   Function: ___

   Source/manufacturer: ___

   Quantity employed: ___

   Point of addition: ___

4. Trade name: Not applicable

   Principal ingredient: ___

   Function: ___

   Source/manufacturer: ___

   Quantity employed: ___

   Point of addition: ___

5. Trade name: Not applicable

Principal ingredient: ______

Function: ______

Source/manufacturer: ______

Quantity employed: ______

Point of addition: ______

H. Equipment Specifications

1. Electrostatic precipitator(s)

Number: Two

Manufacturer: Pollution Control - Walther

Design removal efficiency: 99.8

Outlet temperature: 135°C (275°F)

Pressure drop: 0.13 kPa (0.5 in. H_2O)

2. Mechanical collector(s) - Not applicable

Number: ______

Type: ______

Size: ______

Manufacturer: ______

Design removal efficiency: ______

Pressure drop: ______

3. Particulate scrubber(s) - Not applicable

Number: ______

Type: ______

Manufacturer: ______

Dimensions: ______

Material, shell: ______

Material, shell lining: ______

Material, internals: ______

No. of modules per train: ______

No. of stages per module: ______

No. of nozzles or sprays: ______

Nozzle type: ______

Nozzle size: ______

Boiler load capacity: ______

Gas flow and temperature: ______

Liquid recirculation rate: ______

Modulation: ______

L/G ratio: ______

Pressure drop: ______

Modulation: ______

Superficial gas velocity: ______

Particulate removal efficiency (design/actual): ______

Inlet loading: ______

Outlet loading: ______

SO_2 removal efficiency (design/actual): ______

Inlet concentration: ______

Outlet concentration: ______

4. SO_2 absorber(s)

Number: Four

Type: Vertical, rod-deck (Ventri-Sorber scrubber)

Manufacturer: Riley Stoker/Environeering

Dimensions: 12 m x 12 m x 1.5 m (40 ft x 40 ft x 5 ft)

Material, shell: Carbon steel

Material, shell lining: Not applicable

Material, internals: 316L SS (rods) and Hastelloy G

No. of modules per train: 1 spray zone, 9 rod decks

No. of stages per module:

Packing/tray type: Rod deck

Packing/tray dimensions: 2.5 cm (1 in.) rods spaced 2.5 cm (1 in.) apart

No. of nozzles or sprays: 12 spray heads *

Nozzle type: Open pipe arrangement

Nozzle size: 5 cm (2 in.) flow orifices

Boiler load capacity: 25% *

Gas flow and temperature: 167 m^3/s (353,900 acfm) *

Liquid recirculation rate: 994 liters/s (15,750 gal/min) *

Modulation: 50%

L/G ratio: 6.8 liters/m^3 (50 gal/10^3 acf)

Pressure drop: 20 kPa (8.0 in. H_2O)

Modulation:

Superficial gas velocity: 3.9 m/s (13 ft/s)

Particulate removal efficiency (design/actual): 0/75

Inlet loading: 0.02 mg/m^3 (0.009 gr/acf) (design)

Outlet loading: 0.02 mg/m^3 (0.009 gr/acf) (design)

SO_2 removal efficiency (design/actual): 85.3/91.6

Inlet concentration: 4123 ppm (max. design)/ 3000 ppm (actual)

Outlet concentration: 575 ppm (max. design)/ 252 ppm (actual)

5. Wash water tray(s) - Not applicable

Number:

* Per scrubber module.

Type: ______

Materials of construction: ______

Liquid recirculation rate: ______

Source of water: ______

6. Mist eliminator(s)

Number: Four, one per module

Type: Chevron

Materials of construction: Hastelloy G

Manufacturer: Riley Stoker/Environeering

Configuration (horizontal/vertical): Vertical - 35° tilt

Number of stages: Two

Number of passes per stage: Three

Mist eliminator depth: ______

Vane spacing: 6.4 cm (2.5 in.)

Vane angles: 90-degree sharp-angle bends

Type and location of wash system: Front and back spray (1st stage); front spray (2nd stage).

Superficial gas velocity: 3.6 m/s (12 ft/s)

Freeboard distance: ______

Pressure drop: 0.25 kPa (1.0 in. H_2O)

Comments: Mist eliminator wash-down tanks supply fresh-water and spent wash water for cleaning; 1st stage - 56 liters/s (885 gpm) and 2nd stage - 49 liters/s (775 gal/min)

7. Reheater(s): Not applicable - wet stack

Type (check appropriate category): ______

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

Gas conditions for reheat: Not applicable

Flow rate: ____

Temperature: ____

SO_2 concentration: ____

Heating medium: ____

Combustion fuel: ____

Percent of gas bypassed for reheat: ____

Temperature boost (ΔT): ____

Energy required: ____

Comments: The system is not equipped with a stack-gas reheat system. A wet stack is equipped with hoppers for collection of entrained droplets.

8. Fan(s) - Service for boiler, ESP's, and FGD system.

Number: Four, induced-draft (with respect to boiler)

Type: Centrifugal, double-width, double-inlet, radial tip

Materials of construction: Carbon steel

Manufacturer: Buffalo Forge

Location: Dry, between ESP's and FGD system

Rating: 2960 kW (4000 hp)

Pressure drop: 9.5 kPa (38.0 in. H_2O)

9. Recirculation tank(s):

Number: Four

Materials of construction: Rubber-lined carbon steel

Function: Collection of spent solution/limestone makeup addition.

Configuration/dimensions: 11 m dia. x 6.7 m (37 ft dia. x 22 ft)

Capacity: 606,000 liters (160,000 gal)

Retention time: 10 minutes

Covered (yes/no): No

Agitator: Yes

10. Recirculation/slurry pump(s):

Service	Number	Type	Manufacturer	Capacity	Operation
Slurry recirculation	12	Centrifugal slurry	Worthington	497 liters/s (7875 gal/min)	12 total 8 operational 4 spare
Slurry transfer	4	Centrifugal slurry	Worthington	45 liters/s (705 gal/min)	4 total 1 operational 3 spare

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) - Not applicable

Number: ______________________________

Description: ______________________________

Area: ______________________________

Depth: ______________________________

Liner type: ______________________________

Location: ______________________________

Service Life: ______________________________

Typical operating schedule: ______________________________

____

Ground water/surface water monitors: ______________________________

____

15. Final disposal site(s)

Number: One

Description: Clay-lined settling pond

Area: 263,000 m^2 (65 acres)

Depth:

Location: On site, 0.8 km (0.5 mi) from plant

Transportation mode: Pipeline

Service life: 3 to 5 years

Typical operating schedule: Continuous flow from waste collection tank.

16. Raw materials production - Limestone preparation

Number: Two mills (one operational/one spare)

Type: Wet ball mill, oil-lubricated

Manufacturer: Kennedy Van Saun

Capacity: 36 Mg/h (40 tons/h)

Product characteristics: Slurry - 65 percent solids stream, which is transferred to a mill slurry tank and then to a storage tank for addition to recirculation tank.

I. Equipment Operation, Maintenance, and Overhaul Schedule

1. Scrubber(s) - Not applicable

Design life:

Elapsed operation time:

Cleanout method:

Cleanout frequency:

Cleanout duration:

Other preventive maintenance procedures:

2. Absorber(s) - Not available

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: __________________________

Cleanout frequency: ________________________

Cleanout duration: _________________________

Other preventive maintenance procedures: __________

____

3. Reheater(s) - Not applicable

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: __________________________

Cleanout frequency: ________________________

Cleanout duration: _________________________

Other preventive maintenance procedures: __________

____

4. Fan(s) - Not available

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: __________________________

Cleanout frequency: ________________________

Cleanout duration: _________________________

Other preventive maintenance procedures: __________

____

5. Mist eliminator(s) - Not available

Design life: ______________________________

Elapsed operation time: ______________________

Cleanout method: ____________________

Cleanout frequency: ____________________

Cleanout duration: ____________________

Other preventive maintenance procedures: ____________________

____

6. Pump(s)- Not available

Design life: ____________________

Elapsed operation time: ____________________

Cleanout method: ____________________

Cleanout frequency: ____________________

Cleanout duration: ____________________

Other preventive maintenance procedures: ____________________

____

7. Vacuum filter(s)/centrifuge(s)- Not available

Design life: ____________________

Elapsed operation time: ____________________

Cleanout method: ____________________

Cleanout frequency: ____________________

Cleanout duration: ____________________

Other preventive maintenance procedures: ____________________

____

8. Sludge disposal pond(s)

Design life: 3 to 5 yr

Elapsed operation time: ____________________

Capacity consumed: ____________________

Remaining capacity: ____________________

Cleanout procedures: ____________________

____

J. <u>Instrumentation</u> - See text, Section 3, Process Control subsection.

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: See text of report concerning specific instrumentation and process control network.

____

____

____

K. Discussion of Major Problem Areas: See text of report concerning problem areas.

1. Corrosion: ______________________________

____

____

2. Erosion: ______

3. Scaling: ______

4. Plugging: ______

5. Design problems: ______

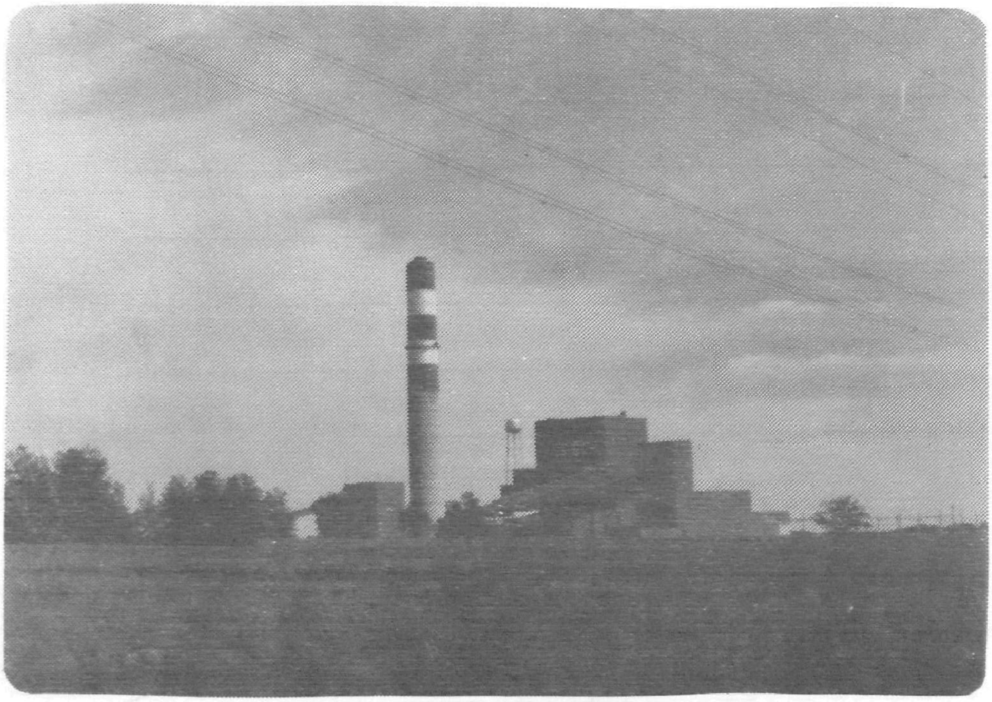
6. Waste water/solids disposal: ______

7. Mechanical problems:

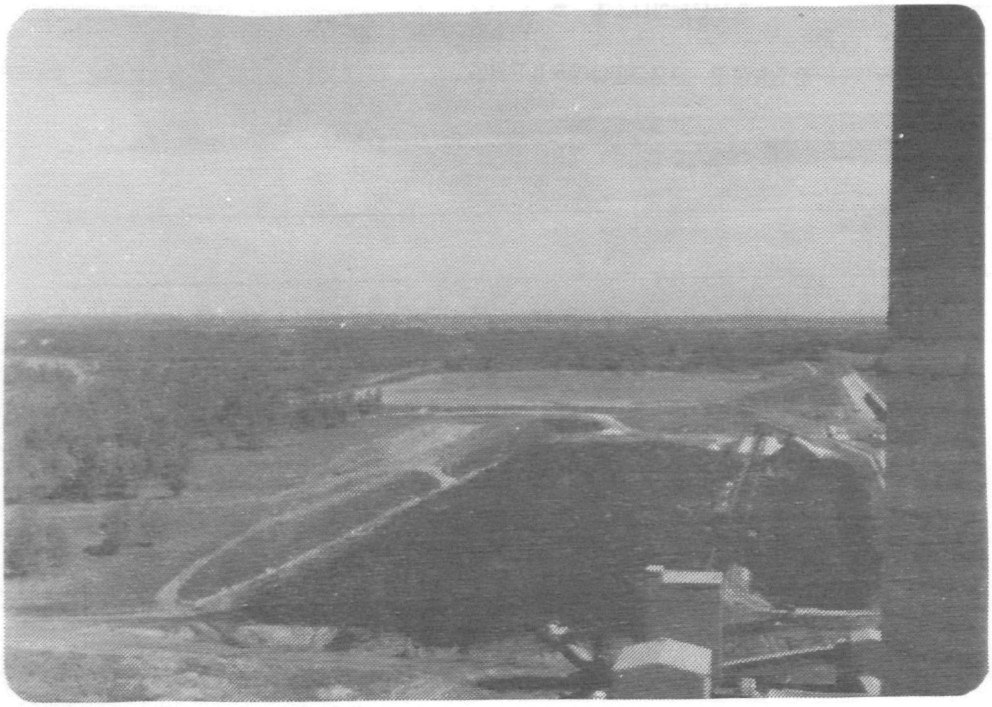
L. General comments:

APPENDIX B

PLANT PHOTOGRAPHS



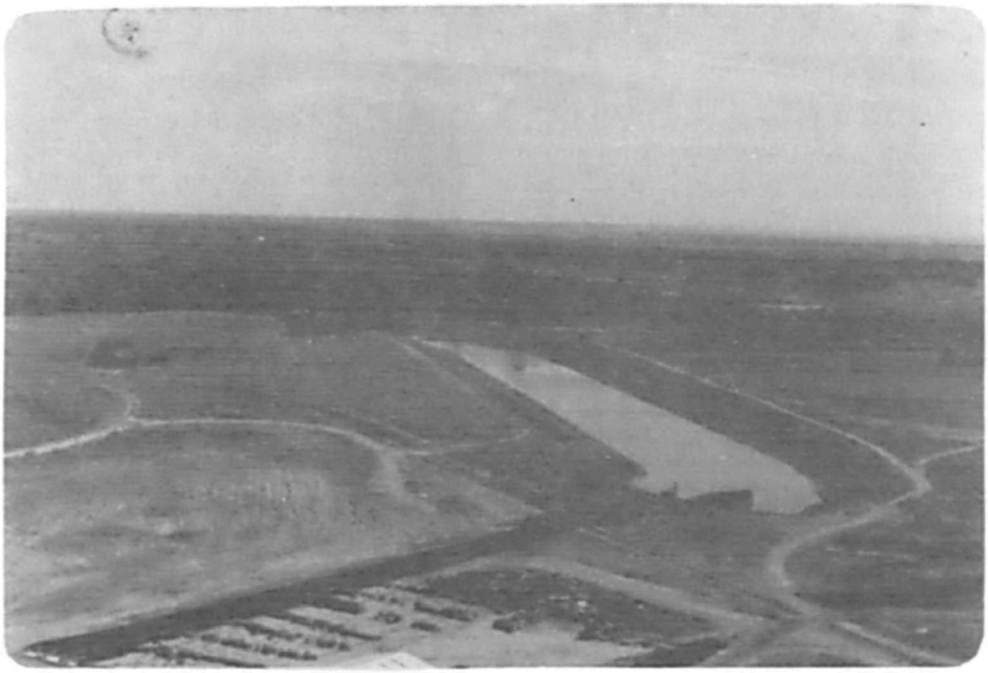
1. View of Duck Creek Station. Featured to the right of the stack are the boiler and turbine houses.



2. View of Duck Creek dead coal storage area. Featured are the stacker/reclaimer (foreground) and waste disposal pond (background). Limestone dead storage is maintained at the far end of the coal dead storage area.

3. View of carbide lime supply kept at the plant site for use during emergency pH control excursions.

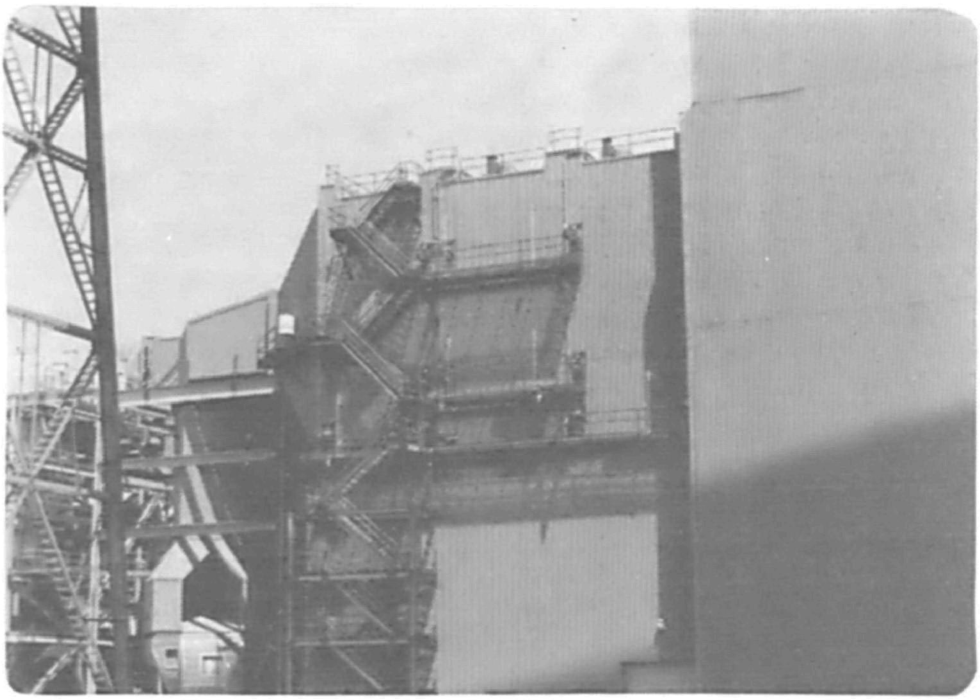
4. View of Duck Creek cooling pond. Inverted weir featured at right allows water to be withdrawn from the deeper, cooler levels of the pond.



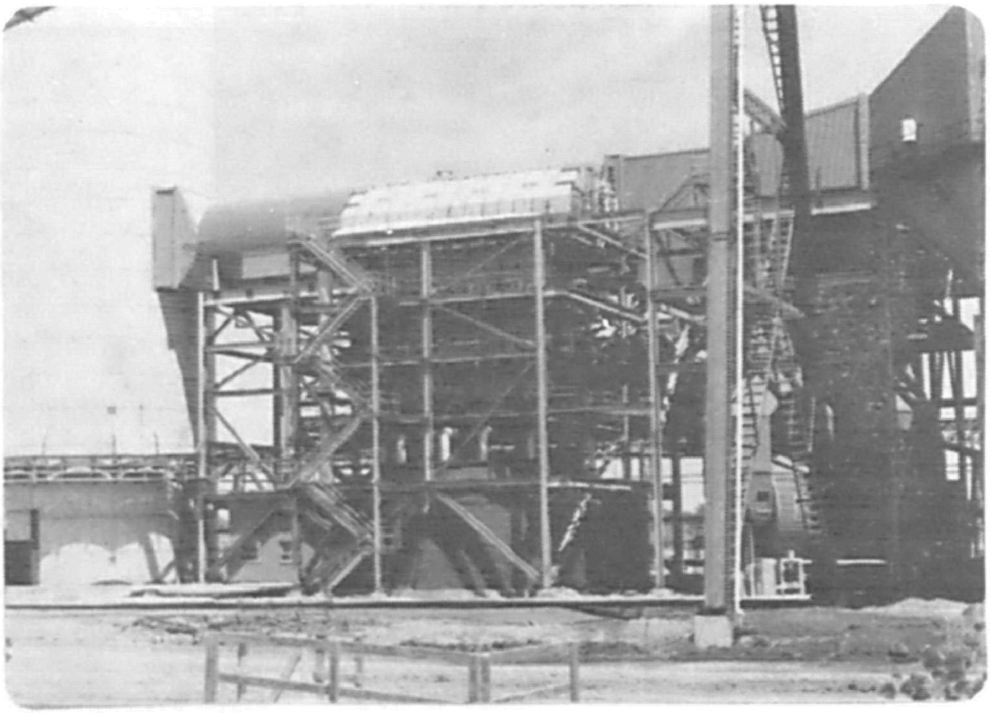
5. Discharge canal for cooling water return to cooling pond.

6. View of waste disposal pond. Featured at far end of pond are fly ash, bottom ash, and scrubbing wastes, which are discharged to pond for final disposal.

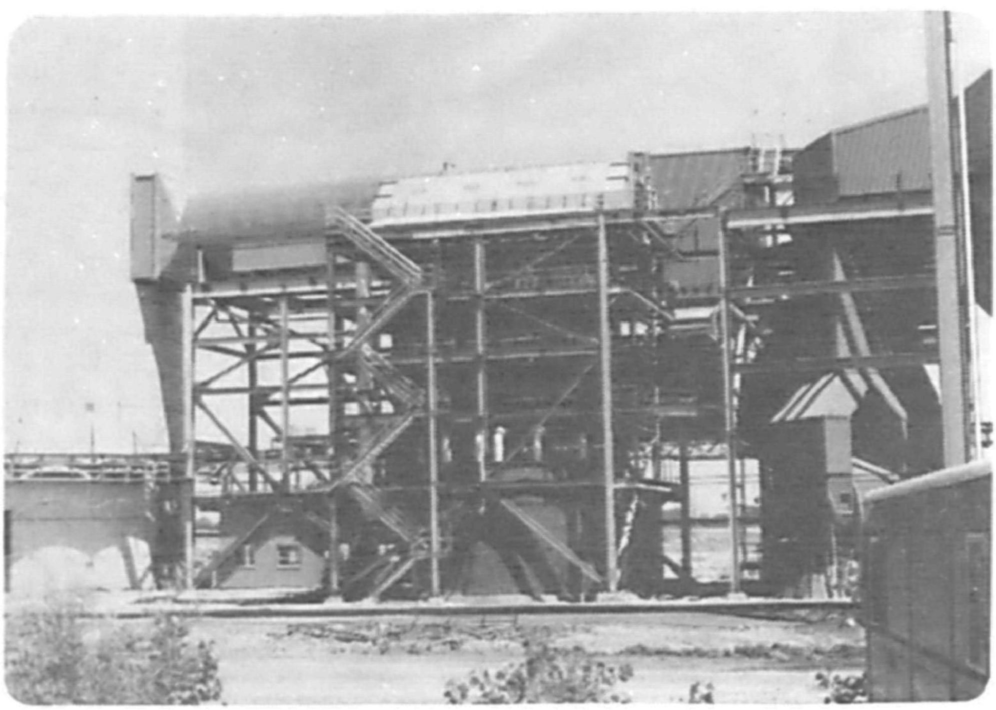
7. View of coal transfer houses and conveyor. The coal transportation network is also capable of handling limestone.



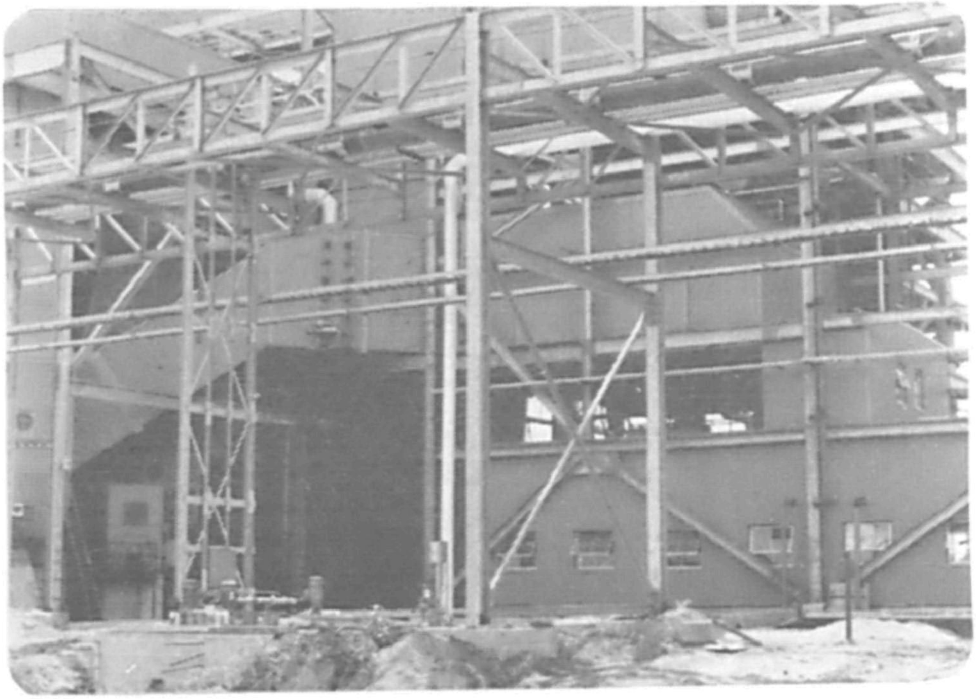
8. View of Duck Creek ESP. Featured at the left is one of the four parallel double-inlet induced-draft fans.



9. Side view of Duck Creek D-scrubber module. Featured from right to left are the ESP outlet duct, induced-draft fan, scrubber module and recirculation tank, bypass breeching, and stack.



10. Side view of Duck Creek D-scrubber module.



11. View of induced-draft fans and discharge duct work. Double-louver seal-air dampers are featured in discharge duct near center of photo.

12. View of top portion of stack. Featured is stack plume with unit operating at full load and ESP's in service during low-sulfur coal combustion.

13. Close-up view of D-scrubber module recirculation tank.

14. Mist eliminator PVC wash piping showing solids deposition incurred during initial operation of D-scrubber module.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES IERL-RTP project officer is Norman Kaplan, Mail Drop 61, 919/541-2556.

16. ABSTRACT

The report presents the results of a survey of operational flue gas desulfurization (FGD) systems on coal-fired utility boilers in the United States. The FGD system installed on Unit 1 at the Duck Creek Station of Central Illinois Light Company is described in terms of design and performance. The system consists of four parallel, wet-limestone, rod-deck scrubber modules designed for 25% capacity each, providing a total sulfur dioxide removal efficiency of 85%. The bottom ash, fly ash, and scrubbing wastes are disposed of in a sludge pond lined with a natural impermeable material. The first module of this four module FGD system was placed in service on July 1, 1976, and operated intermittently throughout the remainder of the year and for approximately one month in early 1977. On July 23, 1978, the three remaining modules were completed and all four modules were placed in the gas path for treatment of high sulfur flue gas.

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	

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