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A Process Cost Estimate for Limestone Slurry Scrubbing of Flue Gas
Part I

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A Process Cost Estimate for Limestone Slurry Scrubbing of Flue Gas Part I

by

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PART I

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I. SUMMARY

A conceptual design and cost estimate were prepared for a wet limestone scrubbing system for removal of sulfur dioxide (SO_2) from the flue gas of a 500 megawatt (mw) steam boiler plant fired with coal that has a concentration of 3.5 per cent sulfur by weight. The wet limestone process is based upon data developed by TVA, Office of Agricultural and Chemical Development, Division of Chemical Development, Process Engineering Branch. This branch has offices in Muscle Shoals, Alabama, and a pilot plant at the Colbert Steam Plant near Muscle Shoals.

The TVA Wet Limestone Scrubbing System removes the SO_2 by contacting a slurry of finely pulverized limestone with the flue gas in a turbulent contact absorption (TCA) scrubber. In the scrubber, the SO_2 in the gas reacts with the limestone, producing a mixture of unreacted limestone and gypsum ($CaSO_4 \cdot 2H_2O$). Before scrubbing in the TCA scrubber, the flue gas passes through a venturi scrubber to remove fly ash. The slurries from the two scrubbers are combined for disposal in a settling pond.

The capital cost for the scrubbing system installed with a new boiler plant was estimated to be $20.15 million, or an incremental cost of $40.30 per kw of installed power. This total cost is broken down in the following table into the total of material, labor, and subcontracts, and the total estimated cost for each of the nine major process areas in the plant.

Table 1

CAPITAL COSTS (IN THOUSANDS OF DOLLARS)

	Direct Cost (Matl., Labor and Subc.)	Indirect Cost (Insur., Taxes, Engr., Superv., Constr., Equip., Ovhd., Fee, etc.)	Total Cost (Direct and Indirect)
Group I Limestone Handling Unit	$ 217	$ 101	$ 318
Group II Slurry Prep. Unit	859	345	1,204
Group III Scrubbing System	5,046	2,078	7,124
Group IV Flue Gas. Disch. Unit	1,988	821	2,809
Group V Reheat System	390	160	550
Group VI Ammonia Unit	37	19	56
Group VII Waste Disposal	4,560	1,695	6,255
Group VIII Entrain. Separ. Recirc.	232	110	342
Group IX Major Elec. Equip.	330	121	451
Misc. Field Direct Costs (Temp. Constr., Supplies, Petty Tools, Field Office Supplies, Telephone, etc.)	681	360	1,041
TOTALS	$14,340	$5,810	$20,150

The operating cost of the wet limestone scrubbing system was estimated to be $7.20 million per year, or 2.06 mills per kilowatt hour of electricity generated. This operating cost includes 11,300 kw of electricity required to operate the scrubbing system, and the fuel for reheating the stack gas with a total heat value of 95.2 MM Btu per hr. The power requirements amount to 2.25 per cent of the total power generated by the boiler plant. The fuel consumption is equal to 1.9 per cent of the total heat input to the boiler.

II. FOREWORD

A. Scope

This report presents the results of the conceptual design and definitive cost estimate for a wet limestone scrubbing system applied to a 500 mw electric generating plant. The estimate covers all equipment from the boiler breeching to the boiler stack. The processing areas included in the design are as follows:

(1) Limestone storage and processing.

(2) Slurry scrubbing system with stack gas reheater and accessories.

(3) Spent limestone slurry settling system and water recovery.

The estimate does not include the normal electrostatic precipitator associated with the boiler. Also limestone unloading and handling systems are not included.

B. Design Basis

The wet limestone scrubbing system was designed to be part of a new installation of a 500 mw power generating plant constructed for utilities use. The boilers will be fueled full time with coal with a maximum concentration of 3.5 per cent sulfur by weight. The detailed design of the system is based upon pilot plant work by TVA, Office of Agricultural and Chemical Development. When placed on stream, the boiler system with wet limestone scrubbing will meet EPA standards for sulfur dioxide (SO_2) emission of 1.2 pounds of SO_2 per million Btu heat input.

C. Basic Assumptions

The design of the wet limestone scrubbing system required certain assumptions to be made to provide a basis for the design. The basic assumptions that were made are as follows:

(1) Plant location will provide land availability for location of settling pond and limestone storage without limitations.

(2) An adequate supply of process water and other utilities is available from the boiler area.

(3) Facilities included with the power house for unloading coal and transportation to storage can be used also for unloading limestone and transporting to the storage pile.

(4) The power plant will be built near an adequate supply of the appropriate grade of limestone for use in the process.

(5) The plant will be constructed in the Midwest area where Cincinnati construction labor rates apply.

In addition to these basic assumptions, other assumptions were necessary and are enumerated in the sections that follow.

D. Future Developments

Pilot plant testing is still in progress, and improvements in the process equipment will probably provide higher efficiency and more reliability in future designs. The first improvement that will contribute to increased reliability is modification of the SO_2 scrubber which now requires excessive maintenance because of frequent plugging. A second area where improvements will be made is in the design of the entrainment separator and the ductwork connecting it to the SO_2 scrubber. This equipment has been a source of plugging problems in the past.

The part of the design that needs the most basic development is the spent slurry handling and disposal system. Although the system included in the design will function adequately to dispose of the waste slurry, a large amount of land is needed for the slurry disposal pond, and the life of the pond is short. Also, construction cost of this portion of the plant is a significant part of the total cost.

III. PROCESS DESCRIPTION

A. General Process Information

The design of this wet limestone scrubbing process for SO_2 removal from flue gas was based primarily upon design data from the TVA, Office of Agricultural and Chemical Development, with modifications suggested by TVA and EPA to incorporate improvements indicated by pilot plant operation.

The process is a scrubbing system of four parallel trains, each with a capacity equivalent to 125 mw. Each train consists of a venturi scrubber, turbulent contact absorption (TCA) scrubber, horizontal entrainment separator, and a flue gas reheater in series. The scrubbers are fed with a limestone slurry.

The limiting size of existing equipment requires four trains for a 500 mw boiler plant. Each train is controlled separately. The flow of flue gas divides equally to the four trains and passes through the venturi scrubber. In this unit, particulates (fly ash) are removed by contact with the limestone slurry. The gas then passes through the TCA scrubber where the SO_2 is absorbed in the limestone slurry and reacts to form calcium sulfite and calcium sulfate. The gas then passes through an entrainment separator to remove entrained slurry before being reheated in a direct-fired gas heater. The gas is re-heated to give it sufficient buoyancy for proper stack operation. An induced draft fan overcomes the pressure losses incurred in passing the gas through the system.

Limestone for slurry production is transferred from a stockpile with a 30-day supply to a silo containing a one-day supply from which it is fed at a controlled rate into the recirculating scrubber stream. Overflow from the scrubber system is pumped to a settling pond where the solids settle out producing a clear overflow that is recycled back to the system.

B. Venturi Scrubber

Approximately 385,000 actual cfm of gas enters each venturi scrubber where it is quenched with water and accelerated to a velocity of 75-125 ft per sec. The water is atomized. A fine dispersion of slower moving water droplets is produced, that captures (by impaction) the particles contained in the gas. The wetted particles decelerate after passing through the venturi throat and grow as a result of agglomeration and condensation. The wetted particles are discharged in slurry form into the sump, and only a small fraction is carried over and collected in the TCA scrubber.

Efficiency of the venturi scrubber is directly related to operating pressure drop. At the specified pressure drop, the scrubber is conservatively rated at five grams per standard cubic foot maximum loading. The pressure drop is controlled automatically to nine inches water column (W.C.) by varying the throat diameter. Satisfactory operation can be attained as low as five inches W.C.

Slurry is recirculated from a collection tank, with small retention time, to the venturi at a minimum liquid-gas (L/G) ratio of 18 gal per 1,000 standard cubic feet per minute. The discharge opening from the scrubber is large to prevent plugging.

The gas flow varies with boiler load. The recirculating liquid flow is held relatively constant; therefore, the L/G ratio will increase at low gas flow rates. This variation does not affect the operation adversely. The venturi scrubber slurry is obtained by overflow from the TCA scrubber, and the concentration is not controlled, so it will depend on the TCA slurry solids content, particulates removed by the venturi, and the water evaporated in the venturi. The concentration should be 20 per cent maximum solids at design conditions and full load.

The slurry in the recirculation tank requires a small agitator with a 10 hp drive motor to prevent settling. If left unagitated for several hours, the solids will pack hard and be very difficult to remove.

The temperature of the entire scrubbing system, including recirculating water, is determined by the adiabatic saturation temperature of the inlet gas, which is 127F for 300F gas. Fresh make-up water to the system will cool this to as low as 114F. An automatic temperature-actuated emergency cooling water system will feed 750 gpm of process water to the tower in case of recirculating pump failure. This will prevent heat damage to the scrubber coating. In the venturi scrubber, the dry flue gas carrying dry particulate matter first comes in contact with the slurry, producing a point where plugging may occur. Frequent cleaning of the venturi scrubber may be required.

C. <u>TCA Scrubber</u>

The turbulent contact absorption (TCA) scrubber is a floating bed type, where the gas flows at ten ft per sec upward through a bed of hollow plastic balls, causing them to move violently in random fashion. The bed is about eight to ten inches in static depth and requires about three inches W.C. to fluidize each of two stages. The limestone slurry is fed into the top of the scrubber and flows down through the floating beds. The SO_2 transfers into the liquid and reacts with the limestone as indicated by the following equations:

$$SO_2 + H_2O \rightleftharpoons H^+ + HSO_3^- \quad (1)$$

$$CO_2 + H_2O \rightleftharpoons H^+ + HCO_3^- \quad (2)$$

$$CaCO_3 + HCO_3^- + H^+ \rightleftharpoons Ca(HCO_3)_2 \quad (3)$$

$$Ca(HCO_3)_2 + HSO_3^- + H^+ \longrightarrow CaSO_3 + 2H_2CO_3 \quad (4)$$

$$CaSO_3 + \tfrac{1}{2}O_2 \longrightarrow CaSO_4 \quad (5)$$

$$CaSO_3 + \tfrac{1}{2}H_2O \longrightarrow CaSO_3 \cdot \tfrac{1}{2}H_2O \quad (6)$$

$$CaSO_4 + 2H_2O \longrightarrow CaSO_4 \cdot 2H_2O \quad (7)$$

Approximately ten per cent of the calcium sulfite is oxidized to calcium sulfate.

The slurry rate is roughly controlled for a minimum L/G ratio of about 40 gpm per 100 standard cubic feet per minute. Higher liquid flow rates or higher gas velocities can result in a sharp increase in pressure drop until "flooding" is reached. At this point, the gas upflow will reduce the liquid downflow, causing liquid hold-up in the scrubbers. The pressure drop will climb steeply, surging will take place, and the scrubber will become inoperable.

The diffused mobile packing utilized in the TCA scrubber allows high liquor and gas flow rates to be used without excessive pressure drops.

Slurry from the scrubber flows into a sump and then into a recirculation tank. Limestone flow to the tank is proportioned by the flow rate of gas through the scrubber train. The set point of a ratio controller is set manually to accommodate changes in coal sulfur content, stoichiometric limestone/SO_2 ratio, and limestone feed slurry solids concentration.

The process is designed for 150 per cent of the stoichiometric rate of limestone required to react with 100 per cent of the SO_2 from 3.5 per cent sulfur coal with 100 per cent conversion of sulfur to SO_2. The system is expected to remove at least 80 per cent of the SO_2 in the combustion gas, and virtually 100 per cent of the particulates.

The solids concentration of the recirculating slurry is automatically controlled to ten per cent solids by adding water to the recirculation tank.

A problem occurs in pH control of the TCA system when the pH drops below the operating range of 5.8 to 6.2. At a pH of approximately 5.4, the limestone becomes unreactive and is incapable of raising the pH. At this point, the pH continues to drop sharply. To counteract this problem, an emergency pH control system and an emergency discharge provision have been included. At a pH of 5.6, liquid ammonia is automatically injected at a stoichiometric rate of 50 per cent by weight required to react with 100 per cent of the SO_2 in the gas. After ammonia is injected, the pH is monitored manually to determine if pH control has been restored within the expected adjustment period of 15 minutes. If control is not restored, the TCA recirculation tank can be discharged manually. The system is designed to discharge and refill completely one tank with limestone slurry and process water in 30 minutes. There is enough slurry in the limestone slurry holding tank to refill completely 24 individual tanks at the proper concentration. Complete replacement of the slurry should not be required frequently since the ammonia system will maintain the pH above the critical value.

The recirculation tank is equipped with a small agitator powered by a 15 hp motor. If left unagitated several hours, the solids will settle and pack hard and be very difficult to break up and remove.

The TCA scrubber is a high maintenance item, subject to scaling and plugging. The polypropylene balls composing the beds have roughly a 1,000 hour operating life. Spray nozzles wear out rapidly, and their use is not recommended.

Due to rapid plugging of other types of demisters, a horizontal two-stage entrainment separator is required to remove carry-over from the TCA scrubber. The entrainment separator includes two chevron fin-type demisters with five gal per min per sq ft of recirculated wash water.

Fresh water with low solids content is needed in the second stage so all process make-up water is introduced at the bottom of the tank, near the outlet to the first stage pumps. Make-up flow is 1,400 gpm, which is about ten per cent of the recirculation flow at full operation. Only a minute quantity of TCA slurry is carried through the entrainment separator. When the stack gas is reheated, it contains about 0.06 grams per standard cubic feet of solids, none of which is fly ash.

D. Combustion Gas Reheater

A reduction in stack gas temperature by wet scrubbing will reduce both the momentum and buoyancy of the stack gas, reducing the distance the plume will rise above the stack after it is emitted. Thus, the effective stack height and plume dispersion will be reduced by wet scrubbing. Humidification of the stack gas is also objectionable because condensation may cause formation of a visible plume giving the appearance of undesirable emissions.

Gas-metal contact heat exchangers that use flue gas or steam are subject to plugging. Therefore, a direct-fired reheater is used to reheat the flue gas for proper operation of the stack. Reheat also reduces the relative humidity of the gas and eliminates possibility of a visible plume. Present and future availability of natural gas is questionable, so low sulfur No. 2 fuel oil is specified in this process. If this fuel is in short supply in the future, desulfurized residual oil can be used.

Oil is fed at controlled pressure from a 700,000-gallon fuel tank (30-day supply) to each of the four trains. The oil flow to each reheater is controlled by the exit gas temperature from the train. The process is designed to reheat the gas to 200F, although lower temperatures may be used, depending upon stack and fan design.

E. Scrubbing System Draft

The scrubbing system is controlled to provide equal flow through each of the parallel trains. This is accomplished by a damper controlling the pressure differential across each fan. The damper is actuated by a controller with its set point provided by a controller sensing the total pressure drop through the scrubber system. This results in a constant pressure drop across the system and equal flow through each train, while individual scrubber resistances may vary due to plugging.

The system is designed to handle the following pressure drops in the scrubbing system:

(1)	Venturi scrubber	9 inches W.C.
(2)	TCA scrubber	6 inches W.C.
(3)	Entrainment separator	1 inch W.C.
(4)	Plugging allowance, Maximum	2 inches W.C.
Total		18 inches W.C.

When the pressure drop across one scrubber train rises to two inches W.C above normal, the control damper will be completely open, indicating that particular train needs cleaning. This may occur from once per week to once per month in each train in normal operation.

Bypass dampers are included that will permit operation at full load when a train is removed from service.

F. Limestone Unloading and Handling

Crushed limestone smaller than 3/4-inch size will be delivered to the plant by boat or train in the same manner as the coal supply. The limestone will be unloaded with the same equipment used for coal.

Limestone is stored in a stockpile containing a 30-day supply or 23,000 tons. This pile will occupy a space about

160 ft in diameter and will be about 80 ft high. A conveyor will transport the limestone from the stockpile to a storage silo containing 770 tons or a one-day supply. This silo can be filled by the conveyor in four hours. A front-end loader will be used to feed the limestone into the conveyor hopper, permitting the complete stockpile to be used.

From the silo, the limestone is fed to three tube mills at a controlled rate through weigh-belt feeders. The feed flow is recorded and totalized for inventory control.

G. Limestone Grinding

The limestone is ground by three tube mills (one spare). Each one measures 7 ft diameter by 21 ft long. The tube mills are arranged for once-through operation with no classification and recycle. A screen is installed on the mill outlet to prevent discharge of oversized product.

Manual control of the water added to the tube mills is adequate to produce a slurry within specifications because the grinding operation is at a constant rate.

An alarm signal from the level controller on the limestone slurry holding tank signals for either one, two, or three tube mills to be in operation if the tank is 90, 80, or 70 per cent full, respectively. The mills are then put on stream by the operator. When the tank is 95 per cent full, the level controller automatically shuts down the mills that are running.

The tube mill control strategy requires the operator to put the tube mills on stream and set the feed water flow, as indicated by a rotameter, to give a product with correct solids content at the discharge sample point. The limestone feed rate is adjusted to produce a discharge particle distribution of 70 per cent minus 200 mesh. This size mill should grind 16 tons per hour to the required size, but grindability of the limestone could cause a variation of 30 per cent, reducing the capacity of the mill to 11 to 12 tons per hour with a product size of 70 per cent minus 200 mesh.

If grinding capacity is critical, it will be necessary to run grindability tests on the limestone before purchase.

H. Limestone Slurry Transfer and Storage

Limestone slurry from the grinding system is discharged into a surge tank at 60 per cent solids. This concentration has been chosen because it provides good handling properties and will not settle out easily. Slurry of this concentration has been reported to remain suspended in an unagitated tank for several days without settling, while a 10 to 20 per cent solids slurry will settle in a few hours.

From the surge tank, the slurry is transferred to a limestone slurry holding tank that provides a one-day supply (150,000 gallons). Since the surge and holding tanks may be located some distance apart, a water flush system is included to wash limestone out of the transfer line, if it is expected to be idle for long periods of time.

The slurry is pumped to each scrubbing train, at controlled pressure, where it is fed through a flow controller to each TCA recirculation tank.

Quick refill of the TCA recirculation tank is accomplished by using the spare pump and a separate six-inch emergency fill line. One tank can be filled in about ten minutes.

I. Solids Handling and Disposal

Slurry overflow from the scrubbing trains is gravity fed to a surge tank and pumped to the settling pond.

The solids contained in this slurry are generally difficult to settle out, concentrating only to about 40 per cent solids. Because of the low compaction of the settled solids, a 250-acre lake, 50 ft deep, is required for a 19-year operating period. When dry, the solids produced by this process have a low bulk density and remain fluid even after stacking for long periods of time. These characteristics make cleaning of the pond and long-term handling difficult. The poor settling characteristics result from the flake-like shape of the $CaSO_4 \cdot 2H_2O$ crystal. If any alternatives for quick settling and periodic disposal of the solids are explored, the settling properties must be carefully considered. A settling rate of 0.04 ton per sq ft per day was assumed to design the settling pond. On this basis, a 0.8-acre settling area is required. The assumed settling rate may be high, and a larger settling area may be necessary.

J. Process Water

Process water feed to the system includes about 1,200 gpm pond overflow and 400 gpm raw make-up water totaling 1,600 gpm of process water required. In addition, the system must be capable of delivering 6,000 gpm emergency fill water; therefore, a 3,000 gpm emergency water pump is supplied in addition to a spare 1,600 gpm process water pump.

The 4,500 gpm of water required for emergency filling, in addition to normal process water flow, will be obtained preferably, from the pond overflow. An alternate source for emergency fill water could be the raw water make-up system that must have sufficient capacity to provide the total demand of 6,000 gpm. The source and supply will vary, depending on the particular layout of the facilities and the nature of the raw water system available.

The design data for this pond system provided for raw make-up water from an outside source. Water requirements were based on typical rainfall of 50 in. per yr, evaporation loss of 25 in. per yr, seepage of 12.4 in. per year, and only the lake area was considered to catch the rainfall. However, if the pond is self-sealing or has a drainage area greater than the pond area, a net yearly overflow may be encountered. Consideration must be given to proper handling and disposal of this overflow and will be discussed in Section IX, Environmental Impact.

K. Reliability, Control, and Operation

Reliability and ease of operation are paramount in power plant operation because of the critical service provided. Therefore, the system includes a large amount of spare equipment. Spare equipment includes complete spare tube mill wet grinder, spare pumps on every vital flow, and bypasses around all critical control valves. An entire spare scrubbing train has been suggested by some power plant operators, although the extra cost involved is fully recognized.

In order to continue operating for reasonable lengths of time when supply problems such as strikes and other disruptions are encountered, storage for a 30-day supply is provided for fuel oil, limestone, and ammonia. In addition, to permit continued operation during plant disruptions, a one-day supply of limestone grinder feed and limestone slurry is provided. Normally, it is expected that only one train will break down at a time, enabling the plant to operate at a 75 per cent load while maintaining emissions within specifications.

The control systems included in this design were selected on the basis of providing a moderate degree of instrumentation. Any individual operator may prefer either more or less controls.

The system is designed to be operated from a control room with one limestone area operator and one scrubbing area operator.

All train start-up and shutdown operations are manual, but once the system is on stream, it should run automatically, responding to varying boiler load. The scrubbing system can be expected to operate satisfactorily down to half scrubber load and possibly less, so the boiler load may be greatly reduced without shutting down individual trains. However, it would be advisable to operate with as few trains as possible to keep the scrubbers at, or near, full capacity, since they are more efficient and easier to control at high flow rates. A prolonged reduction in boiler load would warrant taking one or more of the scrubber trains off stream.

Start-up, shutdown, and operating procedures must be developed, but no particular difficulty in operating the plant is foreseen.

L. Ammonia System

The ammonia system includes a 13,000-gallon tank containing

10,000 gallons of ammonia, leaving a 3,000-gallon vapor space. The tank pressure is controlled to 100 psig by regulating steam to a heating coil. This is sufficient pressure to force liquid ammonia to the scrubbing system at a maximum rate of 6,600 lb per hr (1,650 lb per hr each train). This is 50 per cent of the stoichiometric rate to react with 100 per cent of the SO_2 in the gas.

The system is required to operate immediately at full rate after remaining idle for long periods of time, so the tank heater has a large steam capacity to compensate for sudden pressure losses. The control system will be adjusted to reduce the steam supply gradually after a period of use to prevent control overshoot. A pressure relief valve is installed on the tank to relieve over pressure if the control system malfunctions.

There is enough ammonia storage for about thirty 15-minute adjustments for each train, or a 30-day supply. The tank volume is based on one adjustment per day to all four tanks (four adjustments per day to one tank). This should be a conservative estimate of ammonia usage.

M. Slurry Handling

Properties of the limestone slurry used in this system require special materials and design in the equipment to prevent settling and erosion.

Settling is not a large problem with slurry containing 60 per cent solids. Several days may be required for the solids to settle. At lower concentrations, 10 to 30 per cent solids, the solids settle out in a few hours, pack hard, and are very difficult to remove, requiring a large amount of maintenance time.

Since this is a very abrasive slurry and the pH can drop to three or four, rubber lined pipes are specified for all slurry process and transfer lines, recirculation tanks, and pumps. Straight transfer lines may give satisfactory service without the coating, but coated lines are specified to ensure adequate protection.

IV. DESCRIPTION OF MECHANICAL EQUIPMENT

A. General - Mechanical

Specifications and data sheets for the major mechanical equipment have been developed for the limestone slurry system. The items are outlined below and form the basis for the cost estimate. Reference numbers, such as "D-100" are equipment numbers as shown on the drawings in the appendix. All equipment will meet Occupational Safety and Health Act (OSHA) requirements.

B. Limestone Storage - Area I

1. Stockpile Feeder (D-100) and Limestone Silo Conveyor (D-101)

This equipment comprises the limestone conveyor system. The stockpile feeder will be the mechanical vibrating type complete with a hopper and a manually adjustable hopper plow. The conveyor unit will be a 24-inch belt, 260 feet long with a vertical lift of 80 feet, complete with supporting framework and a head discharge chute. The system will be designed to handle 200 tons per hr of crushed limestone.

2. Limestone Storage Silo (V-103)

This unit is to be of carbon steel construction designed for atmospheric pressure and temperature. The silo will have a volume of 20,000 cu ft and will be complete with required ladders, safety cages, guard rails, and nozzles. All material will meet American Society for Testing Materials (ASTM) requirements.

C. Slurry Preparation - Area II

1. Limestone Slurry Hold Tank (V-105) and Agitator (A-102)

The limestone slurry hold tank will be a 30 ft diameter by 30 ft high, rubber-lined carbon steel vessel. The tank will be equipped with a top entering agitator to maintain solids suspension. All material will meet ASTM requirements.

2. Limestone Slurry Feed Pump and Drive (P-103 A and B)

The limestone slurry feed pump requirements are:

Delivery:	350 gpm
Head:	50 ft
Liquid:	Limestone slurry (60 per cent solids)
Pumping Temperature:	80F
Special:	All wetted parts to be rubber-lined or equal
Type:	Centrifugal
Location:	Outside

3. Limestone Weigh Feeder (D-102 A to C)

Three weigh feeders will be installed under the limestone storage silo to weigh, control, and convey the crushed limestone to the ball mills.

Each feeder will include the following features:

(a) Variable speed drive.

(b) Continuous operation with a range of 20,000 to 44,000 lb per hr (accuracy ± one per cent).

(c) Feeder will be complete with a hopper, skirt, and a regulating gate.

4. Tube Mill Wet Grinder (F-100 A to C)

The wet grinding tube mill system will consist of three steel ball mills suitable for open circuit grinding of limestone. Each mill will be capable of continuous flow of 32,000 lb per hr of limestone solids, in a slurry with water (60 per cent solids concentration, total flow rate 54,000 lb per hr). The mill will grind the 3/4-in. diameter limestone chunks to a product size of 70 per cent concentration of minus 200 mesh limestone powder.

5. Limestone Slurry Transfer Pump and Drive (P-102 A and B)

The limestone slurry transfer pump requirements are:

Delivery:	129 gpm
Head:	100 ft
Liquid:	Limestone slurry (60 per cent solids)
Pumping Temperature:	80F
Special:	All wetted parts to be rubber-lined or equal
Type:	Centrifugal
Location:	Outside

6. Tube Mill Surge Tank (V-104)

The surge tank will be a 4 ft diameter by 4 ft high, carbon steel (coal tar epoxy coated) vessel. The tank will be open top. Material will meet ASTM requirements.

D. Scrubbing System - Area III

1. Venturi Recirculation Tank (V-100 A to D) and Agitator (A-100 A to D)

The venturi recirculation tanks will be 20 ft diameter by 15 ft high, constructed of carbon steel (rubber-lined). Each tank will be equipped with a top entering agitator to maintain solids suspension. All material is to meet ASTM requirements.

2. TCA Recirculation Tank (V-101 A to D) and
<u>Agitator (A-101 A to D)</u>

The TCA recirculation tanks will be 20 ft diameter by 26 ft high, constructed of carbon steel (rubber-lined). Each tank will be equipped with a top entering agitator to maintain solids suspension. All material will meet ASTM requirements.

3. <u>Venturi Scrubber (L-100 A to D)</u>

The scrubber will be the venturi type equipped with an automatically adjustable throat to maintain high particulate removal efficiency at variable gas flow rates. The scrubber is designed to operate under the following conditions:

(a) Characteristics of the inlet gas and slurry:

Inlet gas volume (standard cubic feet per minute)	249,000
Inlet gas temperature (F)	300
Inlet dust loading (grams per cu ft)	5.56
Inlet slurry temperature (F)	127
Inlet slurry rate (gpm)	4,589

(b) Characteristics of the outlet gas:

Gas outlet volume (standard cubic feet per minute)	263,000
Gas outlet temperature (F)	127
Unit total pressure drop (inches W.C.)	9

(c) Guaranteed removal efficiency:

Up to 5.0 grams per standard cubic foot per minute in, and 0.021 grams per standard cubic foot per minute maximum out

The unit will be constructed from carbon steel with Plasite 7122 (a plastic coating) and two-inch Kaocrete (a castable refractory) lining.

4. TCA Scrubber (L-101 A to D)

The scrubber will be the floating-bed type with two active stages and an empty stage between the active stages. The scrubber is designed to handle the following conditions:

(a) Characteristics of the inlet gas and slurry:

Inlet gas volume (standard cubic feet per minute)	263,000
Inlet gas temperature (F)	127
Inlet dust loading (grams per cu ft)	0.021
Inlet slurry temperature (F)	127
Inlet slurry rate (gpm)	10,500

(b) Characteristics of the outlet gas:

Gas outlet volume (standard cubic feet per minute)	263,000
Gas outlet temperature (F)	127
Unit total pressure drop (inches W.C.)	6

(c) Guaranteed removal efficiency:

83 per cent SO_2 removal using 3.5 per cent sulfur coal

The scrubber construction will be of rubber-lined Corten steel.

5. Horizontal Two-Stage Entrainment Separator (L-102 A to D)

The function of this unit is to eliminate any entrainment carry-over from the scrubber before the gas is reheated and exhausted to the atmosphere. The separator is designed for a gas flow of eight ft per sec at a gas rate of 263,000 standard cubic feet per minute at 125F. The complete unit will include a casing (housing), built-in collecting tank, spray nozzles, baffles, chevron type eliminator blades with supports and mounting assembly, and all internal piping.

6. <u>Venturi Recirculation Pump and Drive (P-100 A to L)</u>

The venturi recirculation pump requirements are:

Delivery:	2,590 gpm
Head:	90 ft
Liquid:	Limestone slurry
Pumping Temperature:	127F
Special:	All wetted parts to be rubber-lined or equal
Type:	Centrifugal
Location:	Outside

7. <u>TCA Recirculation Pump and Drive (P-101 A to L)</u>

The TCA recirculation pump requirements are:

Delivery:	5,550 gpm
Head:	85 ft
Liquid:	Limestone slurry
Pumping Temperature:	127F
Special:	All wetted parts to be rubber-lined or equal
Type:	Centrifugal
Location:	Outside

8. Scrubber Sump (V-102 A to D)

This vessel is to be of Corten (rust resistant) steel construction with polyester coating, such as Flakeline 103, and two-inch castable refractory lining, such as Kaocrete. The vessel design will be dictated by the scrubber design of the manufacturer. The basic design includes one large sump (30 ft by 30 ft) with two bottom outlets. The scrubbers will be mounted on top of the sump.

E. Induced Draft Fan System - Area IV

1. Booster Fan Retrofit (C-100 A to D)

This fan will be installed in the retrofit plant. The booster fan will be the double inlet centrifugal type rated at 360,000 cfm (19 in. W.C.). Accessories will include: flanged inlet and outlet connections, wear strip, split housing, access door, dampers or vanes, and drain connection. Fans will conform with standards established by Air Movement Control Association (AMCA).

2. Boiler Induced Draft Fan, New Plant (C-101 A to D)

This fan will be incorporated in the equipment design layout for a new plant. The boiler induced draft fan will be the double inlet centrifugal type rated at 360,000 cfm (32 in. W.C.). Accessories will include: flanged inlet and outlet connections, wear strip, split housing, access door, dampers or vanes, and drain connection. Fans will conform with standards established by Air Movement Control Association (AMCA).

3. Venturi Damper (G-100 A to D) and Bypass Secondary Damper (G-103 A to D)

The venturi and bypass secondary dampers will be used for "shutoff" service and will be the parallel-blade multi-louver type. Each damper will be pneumatically controlled.

4. Bypass Damper (G-101 A to D)

The bypass damper will be designed for positive "shutoff" and will be the guillotine type. Each damper will be pneumatically operated.

5. Fan Damper (G-102 A to D)

The fan damper will be designed for volume control and will be the opposed-blade multi-louver type. The dampers will be located in the discharge duct from the system fans and will be pneumatically operated.

F. Reheat System - Area V

1. Direct-Fired Combustion Gas Reheater (B-100 A to D)

These heaters will be installed in the duct between the fan and entrainment separator exit for the purpose of heating the flue gas to increase the stack draft. The heaters will be the forced draft oil burner type using No. 2 fuel oil. Design will meet Factory Mutual, Factory Insurance Association, and local codes.

2. Fuel Oil Pump and Drive (P-105 A and B)

The fuel oil pump requirements are:

Delivery:	16 gpm
Head:	580 ft
Liquid:	No. 2 low sulfur fuel oil

Pumping Temperature: 80F

Type: Rotary

Location: Outside

3. Fuel Oil Loading Pump and Drive (P-110)

The fuel oil loading pump requirements are:

Delivery: 330 gpm

Head: 100 ft

Liquid: No. 2 fuel oil

Pumping Temperature: 80F

Type: Centrifugal

Location: Outside

4. Fuel Oil Storage Tank (V-108)

The fuel oil storage tank will be 50 ft diameter by 50 ft high complete with rafter supported cone roof, stairway with local platform, and required nozzles and vents. The tank will be constructed of carbon steel and designed for atmospheric pressure. Design will meet American Petroleum Institute (API)-650 standards.

G. Ammonia Injection System - Area VI

1. Liquid Ammonia Storage Tank (V-110)

This unit will be a horizontal pressure vessel complete with a tube bundle for heating the ammonia. The vessel will be 22 ft long by 10 ft diameter complete with required nozzles and safety equipment. Tank will meet American Society of Mechanical Engineers (ASME) design criteria.

H. Waste Disposal System Area VII

1. Slurry Overflow Transfer Pump and Drive (P-104 A to C)

The slurry overflow transfer pump requirements are:

Delivery:	635 gpm
Head:	100 ft
Liquid:	Limestone slurry
Pumping Temperature:	127F
Special:	All wetted parts to be rubber-lined or equal
Type:	Centrifugal
Location:	Outside

2. Process Water Pump and Drive (P-106 A and B)

The process water pump requirements are:

Delivery:	1,540 gpm
Head:	400 ft
Liquid	Water
Pumping Temperature:	80F
Type:	Centrifugal
Location:	Outside

3. Scrubbing System Sump Pump and Drive (P-109)

The scrubbing system pump requirements are:

Delivery:	100 gpm
Head:	50 ft
Liquid:	Slurry
Pumping Temperature:	80F
Special:	Rubber-lined or equal
Type:	Self-priming centrifugal
Location:	Outside

4. <u>Process Water Surge Tank (V-106)</u>

The tank will be a 7 ft diameter by 7 ft high, carbon steel (coal tar epoxy coated) vessel. The tank will be open top. Material will meet ASTM requirements.

5. <u>Slurry Overflow Surge Tank (V-109)</u>

The tank will be a 6 ft diameter by 6 ft high carbon steel (coal tar epoxy coated) vessel. Material will meet ASTM standards.

6. <u>Emergency Process Water Pump and Drive (P-111)</u>

The emergency process water pump requirements are:

Delivery:	3,000 gpm
Head:	400 ft
Liquid:	Water
Pumping Temperature:	80F
Type:	Centrifugal
Location:	Outside

I. <u>Entrainment Separator Recirculation - Area VIII</u>

1. <u>First Stage Entrainment Separator Recirculating Pump and Drive (P-107 A and B)</u>

The first stage separator pump requirements are:

Delivery:	7,210 gpm
Head:	130 ft
Liquid:	Water
Pumping Temperature:	127F
Type:	Centrifugal
Location:	Outside

2. Second Stage Entrainment Separator Recirculation Pump and Drive (P-108 A to C)

The second stage separator pump requirements are:

Delivery:	6,550 gpm
Head:	130 ft
Liquid:	Water
Pumping Temperature:	127F
Type:	Centrifugal
Location:	Outside

3. Entrainment Separator Recirculation Tank (V-107)

The tank will be a 25 ft diameter by 25 ft high carbon steel (coal tar epoxy coated) vessel designed for atmospheric pressure. A baffle in the tank divides the chamber into two equal parts. Construction materials will meet ASTM requirements.

V. INSTRUMENTATION

A. General

The instrument system for the wet limestone scrubbing process is designed to provide control reliability and ease similar to that found in most modern boilers. The scrubbing system is designed for full automatic control of normal operations from the boiler control room with sufficient controls and indications to permit emergency operation from this location also. Initial start-up of the scrubbing system will be accomplished by manually starting individual components locally and transferring control to the control room. The only routine manual operation that will be required is the start-up of the limestone ball mills, to maintain slurry tank level at the normal point. The limestone scrubbing control system is connected to the boiler emergency system for automatic shutdown and by-pass of the scrubbing system in case of boiler emergency. The type of instruments selected for the scrubbing system is consistent with standard chemical process instrument practice, and the installation will be in accordance with the standard practice for this type of plant.

B. Reliability

The requirements of boiler operation include reliability and safety. The wet scrubbing system is designed to match the standards applied to boilers. Since control of firebox pressure is critical to the boiler operation, the controls for the scrubbing system are designed to assure no interruption in the flue gas path. Automatic control of the booster fan provides full compensation for pressure drop across the scrubbing system to prevent back pressure to the boiler. If the fan fails or if the scrubber system becomes plugged, a bypass valve conducts the flue gas directly to the stack. Emission standards severely limit the duration and quantity of particulate emissions to the atmosphere. Direct by-pass of the flue gas to the stack will be permitted only in extreme emergencies.

C. Choice of Instrumentation Types

In the design of the wet limestone installation, it was assumed that process controls will be placed in a central control room associated with the boiler controls. Since the distance between the processing system and the control room may be 300 ft or more, electronic instruments were selected for the design. With electronic instrumentation, the transmission distance does not seriously affect the operation. The use of electronic instruments also reduces the anticipated maintenance on the system and provides some improvement in the reliability of the instrument system.

Reliability is improved in that the instrument calibration remains constant over a long period of time. An additional advantage of using electronic instrumentation is the possible application of computer control to boiler systems. Many types of electronic instruments can be procured with built-in adaptation for computer control. This feature makes electronic instruments compatible with a computer controlled boiler plant.

D. Installation

Miniature indicating controllers were selected for the limestone scrubbing system. These instruments are mounted on a 12 ft long control panel situated in the central control room. Transmitters, control valves, and transducers are connected to the control panel by using standard instrumentation wiring methods employing shielded twisted-pair cable run in conduit. Standard electric practice is followed in the installation of the conduit and wiring system. Control valves used in this system are the standard pneumatic type actuated by current to air transducers located at the valve position. Special large size valves and dampers are equipped with pneumatic actuators connected to the control system by transducers. No electric operators have been used.

All important process variables are recorded on the control panel using miniature strip chart recorders. These recorders use several pens with recordings grouped on each recorder in a logical manner. For the same cost, single point recorders with selector switches for monitoring a large number of less critical variables on a single recorder could be provided. Sufficient process alarms have been provided on the control panel to alert the operator to abnormal conditions in all critical systems. These alarms terminate in a standard annunciator system.

VI. PIPING AND VALVES

A. General

The limestone scrubbing system is required to operate between annual boiler inspections without major maintenance. Therefore, special provisions must be made to prevent damage to the piping and valve systems by the abrasive and corrosive fly ash and limestone slurry. Most of the process streams in this unit contain fly ash or limestone slurry. Also, care must be taken to prevent the slurry from settling in the piping and process equipment. Careful selection of valves and piping as well as provision for flushing, draining, and cleaning helps alleviate this problem.

B. Provisions for Protection from Abrasion and Corrosion

Because of the extremely abrasive characteristics of the limestone slurry, all major piping and equipment in the slurry system are rubber-lined. The rubber-lined pipe and valves should reduce the problem of erosion, thereby extending life of the pipe. As an alternate, some of the straight runs of pipe that will endure a minimum amount of erosion could be supplied in stainless steel. The comparative cost and service life of these two treatments must be investigated to determine the optimum approach. Tanks containing agitated limestone slurry are rubber-lined to prevent abrasion of the tank walls. Agitator impellers and internal parts of slurry pumps are also rubber-lined to prevent wear.

C. Prevention of Settling

The solids contained in the slurry will tend to settle out in any dead space in the piping system. Butterfly valves were chosen because these valves do not have pockets like those found in gate valves. Butterfly valves are also less expensive for the large sizes needed. The piping design provides for continuous recirculation of slurry through all lines normally in service.

Flush connections are provided for those lines that are used infrequently. Access connections for draining and cleaning are provided at strategic points to permit flushing. Cleaning will prevent slurry solids from settling and clogging the system when it is not in operation.

D. Installation

Rubber-lined pipe for all slurry systems is installed with flanges and seals for the rubber lining at each joint. All piping is installed above grade on pipe supports to provide easy access for maintenance and inspection. Sufficient flanges are included in the pipe to permit easy assembly without handling excessively large pieces.

VII. ELECTRICAL

A. General

Cost estimates were developed based upon the following design philosophy. The electrical installation is assumed to be a standard industrial type meeting requirements of the National Electric Code and National Electric Manufacturers Association (NEMA).

B. Power Distribution

Process equipment in the plant is supplied electrical power from motor control centers and unit load centers. The 13.8 kv, three phase, 60 Hz power will be supplied from at least two sources to provide reliability. The cost of installation of these power sources is not included in the estimate. Four load centers with tie breakers will transform and feed power to four motor control centers at the 480-volt level. A double-ended load center will transform and feed power to two 4,160 volt-motor control switchgear groups. The tie breakers are normally open in both of the load centers. Motors of 200 hp or less are controlled from the 480-volt motor control centers. Motors over 200 hp are controlled by the 4,160-volt motor control switchgear groups. Each of the four 480-volt motor control centers feeds one of four scrubbing units. Common equipment is divided among the four motor control centers (MCC).

C. Load Centers

1. 480-Volt Load Centers

The 480-volt load centers are of outdoor weatherproof construction. The 13.8 kv incoming line on each transformer is connected to a single source of power. If a primary disconnect switch or selective switches to provide alternate connection of sources are used, additional funds must be included in the estimate. Transformers are specified as oil-filled, 65C temperature rise units. The 480-volt switchgear housing is metal-clad, outdoor, walk-in type. This switchgear unit houses the four main and three tie breakers with provisions for four future breakers. All breakers are manually operated with standard trip units and without ground fault relaying. A main ammeter and voltmeter, with switches, is provided on each train. Neutral and ground leg are common at this point which is considered the source. The load centers are located as close to the control centers as practical.

2. <u>4,160-Volt Load Centers</u>

The 4,160-volt load centers are of outdoor, weatherproof, metal-clad construction. A 13.8 kv incoming line on each transformer is connected to a single source of power. If switches to provide alternate primary connections are installed, additional funds must be included in the estimate. The two transformers are specified as oil-filled, 65-degree temperature rise. The 4,160-volt motor control housing is of outdoor, metal-clad, walk-in construction. This equipment is fed by one transformer at each end and is isolated by a secondary main breaker. A tie breaker is placed in the middle of the bus. Eight 4,160-volt motors will be placed on one bus and seven on the other with provisions for one to be accommodated in the future. The 4,160-volt motor controllers are all of the full voltage, non-reversing start type. Three phase overload protection is provided. No interlocking, voltmeters and ammeters, or ground fault-detection are included. The load center and the motor control center will be located as close to the loads as possible, preferably half way between the most distant motors.

D. Motor Control Centers

Motor control centers for 480-volt motors are the weather-proof, non-walk-in type. Main disconnects are not provided because of the close proximity of the load center feeder breaker. A neutral bus is provided in the one motor control center equipped with the lighting feeder breaker. A ground bus is provided in all motor control centers. Starters are equipped with combination circuit breakers, and are full voltage, non-reversing types with overload protection in all three phases. Individual 120-volt control power transformers and external reset buttons are also included. No ammeters, running lights, or stop-start pushbuttons are included in the motor control centers. The motor control centers will be located as close to the loads as space permits.

E. Power Supply

The cost of installing incoming power supplies is not included in this estimate. At least two feeders from two sources are required for the six transformers. This cost estimate includes all equipment at the primary terminals and beyond. The method of wiring (that is, conduit, aerial, or underground cable) used in installing the power supplies is to be specified by the organization providing the power source.

F. Wiring Methods

The basic wiring method applied uses galvanized rigid conduit with single conductor cables. Conduit is run exposed on pipe supports. Each motor is fed by a separate conduit. Motors over 50 hp have separate conduits for control wiring. Wire for 480-volt service is Type THW. Control wiring is standard No. 14TWN type wire. Control runs to the control panel are grouped in multi-conductor control cable. All wire will be color coded. Cable for 4,160-volt service is a shielded single conductor, with 5 kv cross-linked, polyethylene insulation. Pushbuttons and other wiring devices are mounted near equipment served in cast weatherproof boxes. Myers hubs, or equivalent, are used to attach conduit to sheet metal enclosures that are of the seam-welded type with gasketed covers. No explosion proof equipment is included.

G. Grounding

A ground loop is provided with No. 4/0 bare copper wire. The steel structure is grounded at every other column. All major vessels are grounded to the ground loop. All large motors, load centers, transformers, and motor control centers are also grounded to the main ground loop.

H. Lighting and Receptacles

General area lighting is provided by 277-volt mercury vapor fixtures. Lighting level is provided for incidental night time inspection only and is estimated at 25 foot-candles. One lighting panel will serve all four units, and fixtures will be switched at the panel. Weatherproof 120-volt service receptacles are provided in the area so that any spot may be reached with a 100-foot drop cord. Two 60-amp welding receptacles are provided for the four units. No special instrument or gage lighting is included in this estimate.

I. Electrical Instrumentation Controls

Motor control wiring for motors 50 hp and below is installed in the same conduit with the motor power wiring. Motors above 50 hp require a separate conduit for control wiring from the motor control center. A local stop-start pushbutton is provided at each motor. Wiring for pressure switches and other devices associated with control of a particular motor may be installed with the pushbutton wiring for that motor. Instrument wiring is grouped where possible. Master terminal boxes and multi-conductor control cable are used where economically feasible.

Labor is included for component installation, adequate labeling of all wiring and termination. Remote pushbuttons, running lights, and shutdown alarms are included on a main control panel for all critical motors. Instrument connections are estimated on a per unit basis, and a wiring allowance is made for each field instrument. The cost for wiring panel instruments and material cost for panel pushbuttons is included in the instrument budget.

J. Miscellaneous

Cost of communications, telephone systems, or fire alarm systems is not included in this estimate. No allowance has been made for any special treatment such as polyvinyl chloride (PVC) coated conduit for salt mist areas.

VIII. CIVIL AND STRUCTURAL

A. Slurry Settling Pond Design Parameters

1. General

Design criteria specify a settling basin having a water surface area of 250 acres and a liquid depth of 50 feet. Such a basin would have a useful life of 19 years, based upon an inflow rate of 1,060 gpm and 80 per cent service factor. Precipitation gain was estimated to be 595 gpm, and losses due to evaporation and seepage were estimated at 368 gpm and 148 gpm respectively. The resultant overflow rate was 1,139 gpm.

2. Settling Pond Design

No specific data were available regarding terrain, and no ground water information was available. Therefore, a hypothetical settling basin was designed as a perfect square. Waterline dimensions were established at 3,165 feet per side, and dike slopes were specified at 2:1 maximum. This configuration yields 10,780 acre-feet of storage capacity.

3. Dike Design

The retaining structure is specified as an earth dike with a 24-inch clay blanket liner on the dike sides and bottom within the reservoir. The pond bottom may be left unlined if ground water does not flow into the pond, and if seepage from the pond does not contaminate ground water in the vicinity. The unlined bottom permits seepage to reduce the probability of a net overflow. If environmental damage is possible from the seepage, the pond must be lined as designed with a 24-in. clay blanket throughout. This problem is discussed further in Section IX, Environmental Impact. The berm of the dike was made sufficiently wide to accommodate a 20-ft service road around its entire periphery, although the roadway was not included in the estimate.

4. Erosion Control

Erosion control against wave action (waves were calculated at 2.5 feet in height under an assumed 40-mph wind) is provided by a 26-foot wide butyl rubber sheet laid from the top of the berm to a position below the normal water level.

5. Inlet Structure

The inlet structure was assumed to be a simple concrete splash apron set into the interior face of the dike berm.

6. Outlet Structure

The outlet structure was designed to provide positive control of water depths in increments of ten feet. Control is accomplished by using coupled slide headgates covering 18-in. by 18-in. openings. The openings are in a conventional reinforced concrete box culvert set into the interior face of the dike. The outlet of the culvert discharges through the dike slightly below the ten ft water level. It is assumed that the outlet gates will be used below maximum level only during the initial filling period. Normal operating level will be controlled by the 50-ft or 40-ft gates.

B. Structural and Foundation Design Basis

The design basis for the structural supports and foundations for process equipment and piping is listed below:

(1)	Structural steel:	American Society for Testing Materials (ASTM) A36
(2)	Reinforcing steel:	Grade 40 ASTM A615
(3)	Concrete:	Compressive strength of 3,000 psi
(4)	Soil bearing value:	3,000 psf
(5)	Frost line:	1 ft 6 in. below finished grade
(6)	Wind:	25 psf height zone
	(a) 0 ft to 30 ft	20 psf
	(b) 30 ft to 49 ft	25 psf
	(c) 50 ft to 99 ft	30 psf
(7)	Wind shape factor:	0.6 for silos
(8)	Equipment weight to mass ratio:	3 to 1
(9)	Roadway clearance:	22 ft

C. Facility Description

1. The flue gas scrubbing facility is located outside of the boiler building, with a slab-on-grade 146 feet wide and 198 feet long. Trenches are provided that discharge into a chemical sump pit.

2. The horizontal two-stage entrainment separators, gas reheaters, bypass secondary dampers, TCA scrubbers, venturi scrubbers, and scrubber sumps are supported with structural steel columns and beams, braced vertically and laterally.

Stairs are provided to the service platforms, and one escape ladder is provided for emergency use.

IX. ENVIRONMENTAL IMPACT

A. General

Any process designed to remove pollution from any phase of nature cannot eliminate the polluting substance, but can only change it from one form to another. The ideal situation would be to change the pollutant from its original form to a second form which is not a pollutant and has value in the economy.

The removal of sulfur dioxide from powerhouse stacks, follows this pattern, changing the sulfur dioxide from a gas to a pure concentrated liquid or to a liquid or solid compound. The resulting product must be in a form to produce the minimum amount of pollution and require the lowest cost for handling and disposal. Any consideration of the wet limestone scrubbing process must take into account certain aspects of possible pollution that will be encountered.

B. Sources of Possible Pollution

The wet limestone scrubbing process is designed to reduce the sulfur dioxide emissions from powerhouse stacks to below the level required by the standards when burning coal that has a maximum of 3 to 3.5 per cent sulfur content. If coal with a higher sulfur content than this range is used, the sulfur dioxide emissions from the stack may exceed the limits provided for in the standards. If it is necessary to use coal with a higher sulfur content, improvements in the efficiency of this process or the substitution of a more efficient process will be required. Control of particulate emissions is provided by the wet limestone scrubbing process. However, a failure in the process requiring bypassing of flue gas directly to the stack will violate the standard for particulates as well as sulfur dioxide. No provisions are made for removing particulates from stack gas when the limestone system is out of service; therefore, the amount of particulate emissions will be large when the system is not in operation. A failure of part of the system, requiring the shutdown of one of the parallel scrubbing trains, will not necessarily produce emissions exceeding the standard if the remaining trains are capable of handling the full flow of stack gas. If the larger flow of gas through the remaining trains exceeds their capacity, sulfur dioxide emissions will increase. Liquid and solid materials entrained in the gas from the limestone scrubber are removed by the entrainment separators. A failure of the separators will cause an increase in particulate matter from the stacks. This particulate emission will be limestone and limestone derivatives from the slurry scrubber.

The wet limestone scrubbing system can contribute to water pollution in several ways. The most likely source of pollution will be from overflow of excess water from the settling pond where the net rainfall exceeds the evaporation, seepage, and process losses. When these conditions exist, a net overflow from the pond may require further processing to prevent contamination of water courses receiving effluent from the plant. Short periods of excess rainfall can be accommodated by the freeboard existing in the settling pond. The amount of freeboard can be adjusted to accommodate requirements for short term increases in the amount of water accumulated. Short periods of rainfall should cause no serious complications because the settling pond is designed to collect only the rain that falls directly into the pond. If there is excess seepage of liquid from the pond, streams and ground water will be contaminated. Water pollution factors vary according to location and climate; therefore, a thorough evaluation of all conditions will be required for each instance.

Additional air and land pollution can be caused by dust from dry storage facilities for limestone and the residue materials. Although the limestone arriving at the plant will have a particle size of approximately 3/4-in., the loading, storage, and handling operations may produce sufficient dust to constitute a nuisance in the local area. If this situation arises, it may be necessary to provide water sprays or other means to reduce the amount of dust. If at any time limestone, gypsum, and fly ash are removed from the slurry pond and dried, the problem of dust contamination exists for the surrounding area.

The wet limestone scrubbing system will be installed in power plants to permit use of high sulfur coal or oil. Using high sulfur fuel in larger plants will conserve the low sulfur fuel for use where scrubbing systems are unsuitable. The low SO_2 emissions from the scrubber system must be maintained while reheating the flue gas after the scrubber. Therefore, reheat requires low sulfur fuel. A net saving in low sulfur fuel is obtained because the re-heat fuel quantity is small compared to the primary boiler fuel (about five per cent). The availability of limestone of the proper quality must also be considered when planning a limestone scrubbing system. The quantity of limestone required is large and must be disposed of after use in the process. Therefore, limestone supply and disposal are important to long-term successful operation.

C. Precautions Against Pollution

Precautions against water, air, and land pollution are included in the design. Other precautions must be observed in plant operation to prevent pollution. Four parallel scrubber trains are included in the design. This parallel arrangement will permit shutdown of one train at a time for maintenance while the other three trains continue to operate with the boiler at reduced capacity.

In this way, SO_2 and particulate emissions can be maintained within limits while maintenance is performed. A stockpile of limestone and a supply of slurry are provided so normal maintenance can be performed on the conveyor and slurry system without a plant shutdown. Normal leakage from the process equipment in the scrubbing area will be collected in trenches and a sump and will be pumped to the slurry settling pond.

The design for a specific location must take into consideration all possibilities of accidental spillage. Methods must be included to prevent spills from reaching water courses.

X. COST ESTIMATE

A. Introduction

The estimated capital cost for a wet limestone scrubbing system for installation with a new 500 megawatt coal-fired steam boiler plant is $20,150,000. This total which represents approximately $40.30 per mw of installed capacity will be explained in detail in the sections following.

Summaries of capital cost for the complete plant, and by areas, are given in Appendix I. Also included is detailed information such as the cost of the induced draft fan and unit cost for ductwork. The ductwork cost can be used for estimating the ductwork in a retrofit installation in an existing power plant.

The operating cost for this plant is estimated to be approximately $6.95 million per year. This total operating cost represents 2.0 mills per kilowatt hour of power generated.

B. Capital Costs

1. General

The capital cost estimate developed for this plant is based upon the factors described in the following sections. The cost as presented in the summary sheets in the appendix is broken down into eight sections representing logical operating units. As far as possible, the common services for these units are prorated for each unit. However, such items as substations, waste disposal systems, and water supply are listed separately as common units.

The construction labor for installation of the wet limestone scrubbing plant is based upon labor rates for the City of Cincinnati, Ohio, estimated for the year 1973 (see Schedule in Appendix I). These labor rates are used to present a maximum cost for the installation. The amount of labor required for construction of each portion of the installation is based upon standard labor units used by Catalytic, Inc., in its normal engineering procedures.

Subcontracts for installation of equipment are included only when installation was quoted by the vendor of the equipment for erection of the equipment on the jobsite. All other installation costs are included in the general estimate to provide a better picture of labor and material costs.

A contingency factor of ten per cent was added to the total cost.

Some services and facilities such as process water supply, fencing for the general scrubber area, land for installation of the scrubber system, and instrument-air facilities are considered to be included in the adjoining power plant. No cost was added for providing separate facilities for the scrubbing system

2. Major Equipment

The price of all major equipment was obtained from vendor quotations. Where possible, several quotations were obtained, and the least expensive quotation that met the specifications was selected for inclusion in the estimate. In several instances, only one quotation could be obtained and each is included as a typical cost. The Corten steel breeching material costs were quoted by the vendor, and the fabrication and erection costs on site were estimated using standard Catalytic labor units. Similarly, installation costs were estimated for all other major items of equipment. If the scrubbing system was installed in an existing plant, the labor cost would increase 30 per cent to 50 per cent because of reduced efficiency.

3. Piping and Field Testing

A detailed pipe, valve, and fitting list was made from piping and instrument diagram (P&ID) flowsheets and equipment and piping layout drawings. Most of the carbon steel materials were estimated by using quoted prices, although some small size pipe was estimated using standard rates. Most of the neoprene-lined pipe, valves, and fittings were estimated based upon quoted costs. Some items of neoprene-lined equipment were estimated, based upon earlier equipment costs from Catalytic, with an escalation factor added for updating to 1973 costs. All of the large size neoprene-lined valves included in the estimate are sizes and types which were quoted and are available from vendors.

All of the pipe fabrication except neoprene lining is priced as fabricated on the jobsite, using standard Catalytic man-hour units.

The cost of testing piping systems after construction was estimated by using a percentage of the labor for installing the pipe.

4. Sewers

Storm sewers for the scrubbing area are not included in the estimate but are assumed to be a portion of the general site facilities for the boiler plant. Chemical drains, including concrete trenches and a sump, are provided in the scrubber area. The cost of the concrete trenches and sump are included in the concrete section.

5. Instrumentation

The cost of instrumentation for the plant was determined from a detailed instrument list, using vendor quoted prices for all field and panelboard instrumentation. Installation materials for mounting instruments was estimated and based upon instrument hardware cost. The cost of the panel for centrally mounting control instruments is included in the estimate, but no control room costs are provided because it was assumed that the instrument panel will be mounted in the central boiler control room.

6. Electrical Installation

The estimate of cost for the electrical system was determined from a detailed list of hardware from the electrical one-line diagram. Major electrical equipment was priced through vendor quotations, and field installation costs were determined by estimating length of conduit runs from prime movers to motor control centers. The cost of all motors is included in the price of the equipment being driven. Installation labor for the electrical system is based upon Catalytic standard labor units.

7. Concrete

The amount of concrete required for installation of equipment foundations and operating area concrete pad was determined from detailed designs based upon equipment size and weights. The estimated cost of the concrete is based upon standard Catalytic units for material and labor costs.

8. <u>Structural Steel</u>

The quantity of structural steel required is based upon detailed design of equipment and piping supports. Access platforms, stairways, and ladders are provided for all major equipment located above grade. Steel is included for construction of a pipe bridge across one road between the scrubbing unit and settling pond. The material and labor cost for structural steel work was estimated by using the quantity obtained from the design and application of Catalytic standard unit prices for material and labor.

9. <u>Site Work</u>

The only site preparation included in the estimate is for construction of the waste slurry settling basin. The major site preparation of the scrubbing area will be included in the construction of the boiler plant site. The cost of earthwork for construction of the settling basin and dikes is based upon actual quantities of earth to be moved and a standard unit price for earth moving. The special rubber lining used to prevent erosion of the dike is based upon vendor quotations.

A fence is provided around the settling pond approximately ten feet outside the dike area. No fence is included for the scrubber area because this area will be within the battery limits of the boiler plant. The estimate does not include roads to the settling pond. Roads in the scrubbing area are included in the boiler plant cost estimate.

10. Insulating and Painting

Insulation is provided on the breeching to prevent injury to persons in accessible areas. Insulation is provided to prevent freezing of exposed water lines. No insulation is provided on the process equipment.

The cost of painting was estimated by using Catalytic standard unit prices for the equipment and pipe length. Pipe quantities are based upon a detailed pipe list.

11. Fire Protection

Fire protection is provided in the estimate by the inclusion of four dry chemical wheeled fire extinguishers mounted in storage houses. No other type of fire protection is included in the estimate.

12. Contractor Overhead

Miscellaneous direct costs on the jobsite, for items such as construction supplies, small tools, and temporary facilities, were estimated by applying appropriate percentages to the total direct labor.

Risk insurance is provided in the estimate at 0.4125 per cent of the total job cost.

Sales tax was estimated for an installation in Ohio at four per cent of the cost of appropriate materials.

Payroll burden was estimated at 11.9 per cent of the total construction labor.

Supervision and office personnel costs on the jobsite were estimated at 15 per cent of the total labor cost. The cost of construction equipment was estimated at 12 per cent of the total cost of labor required for construction.

13. Engineering Costs

The cost of engineering design of the wet limestone scrubbing system is included in the estimate at 12 per cent of the subtotal of material, subcontracts, labor, and other costs on the jobsite.

The engineering contract overhead and fee is included at five per cent of the job subtotal.

14. Land Requirements

The cost of land for installation of the scrubbing unit was not included, because this unit will be installed adjacent to the power plant and within the power plant battery limits. Additional land must be provided for limestone storage and the limestone settling pond. These facilities require 300 acres, and the cost of this land is not included in the capital cost estimate.

C. Capital Cost - Retrofit Installation

The detailed capital cost estimate presented in this report is for a wet limestone scrubbing system engineered and installed as part of a new power plant installation. If the scrubbing system is to be installed in an existing plant, the total unit cost will be higher than for the new installation. This cost increase is primarily because of the less efficient arrangement of the equipment and the increased difficulty in completing the installation with minimum disruption of the power plant operation.

The additional cost of installing the same process in the "retrofit" example was estimated on an "order of magnitude" basis using the equipment arrangement of the TVA Colbert Steam Plant as a typical model. Escalation factors were applied to the parts of the estimate that are affected by the change in arrangement and work efficiency. The estimates include all indirect as well as direct costs.

Areas of increased cost and the assumed escalation factors are as follows: The amount of piping was assumed to be 30 per cent higher for a total increase of $423,000. The longer duct work required was estimated by using the incremental cost shown on page 62 and a 100 per cent increase in the length. The increased cost is $1.7 million. The supporting structure was assumed to increase by 50 per cent at an increased cost of $662,000. Labor efficiency was estimated at 80 per cent for the new installation but was assumed to be only 50 per cent for the retrofit case. This reduction in efficiency will increase the overall labor cost by $2.03 million for construction labor and by $1.1 million for subcontract labor.

The total increase in cost of the retrofit ($6 million) does not include cost of removal of existing equipment to permit construction of the scrubbing system or additional cost of the waste disposal settling pond that may be required for a specific location.

The total capital cost estimate for the wet limestone scrubbing system installed on an existing 500 megawatt power plant is $26.15 million. This corresponds to an incremental cost of $52.30 per kilowatt of installed capacity.

D. Operating Cost

The first year operating cost for the SO_2 removal system is estimated at $7.2 million or 2.06 mills per kilowatt hour generated. A tabulation of the operation cost is given in Appendix 2. This estimate is based upon unit cost data taken from the Kellogg Report[(1)] and from design factors of the process described in this report. A breakdown of the cost of operating materials and utilities by processing area is also presented in Appendix 2.

Two men per shift should meet the minimum manpower requirement after normal operations are achieved. No operating labor was included for limestone unloading and handling, security, laboratory testing, or other services that may be required. These services are integrated with the powerhouse services and are part of the powerhouse overhead costs. The scrubbing system will share operating supervision with the powerhouse.

Maintenance cost for the proposed system is uncertain because of lack of experience in operating a plant of this kind and size. Initial maintenance cost may be higher if problems are encountered with materials of construction and plugging.

The cost of capital invested in the plant was fixed at eight per cent to agree with the Kellogg Report. The eight per cent rate is variable and must be considered on a current basis for any detailed evaluation of operating cost. Other factors, such as accelerated depreciation and tax credits, may affect the financial portion of the estimate.

[(1)] Evaluation of SO_x - Control Processes. Kellogg, M. W. Co., Task No. 5. Final Report to Environmental Protection Agency, Contract CPA 70-68. October 15, 1971. PB 204-711.

XI. APPENDICES

Appendix 1

Estimating Summary and Sub-Summary Sheets

Appendix 1

LABOR RATE BREAKDOWN
Union Labor Rates for Cincinnati, Ohio
(Period, Jan. 1973 to June 1973)

	Journeymen ($ per hr)	Foremen ($ per hr)
Asbestos Workers	10.70	11.20
Boilermakers	10.33	10.83
Bricklayers	10.56	10.81
Carpenters	10.35	10.90
Cement Masons	10.34	10.59
Electricians	9.80	10.68
Ironworkers	10.65	11.00
Laborers	8.10	8.35
Millwrights	10.58	11.08
Operating Engineers	10.45	10.95
Painters	9.28	9.53
Pipefitters	10.92	11.42
Teamsters	6.50	-
Sheetmetal Workers	10.29	10.54

INCREMENTAL COST OF BREECHING SYSTEM

Cost of Main Breeching Duct - Incl. Insul., All Indirect Costs

Total Cost	$1,330,000 - For 1,500 linear ft
Unit Cost	$ 890 per linear ft

Cost of Bypass Breeching Duct - Incl. Insul., All Indirect Costs

Total Cost	$ 362,000 - For 550 linear ft
Unit Cost	$ 660 per linear ft

Cost of One Induced Draft Fan - Incl. Insul., Foundation, All Indirect Costs

Total Cost	$ 54,000
Unit Cost	$ 54,000 per fan

SUMMARY SHEET

ESTIMATE/JOB. NO. 41940 (Task No. 11 - EPA 68-02-0241) DATE August 30, 1972
CUSTOMER Environmental Protection Agency Page 1 of 12
LOCATION Site Undetermined
DESCRIPTION A Process Cost Estimate for Limestone Slurry Scrubbing of Flue Gas

MATERIAL	6	218,	700
SUBCONTRACTS AND SHOP LABOR	5	546,	300
ALL RISK INSURANCE, LEGAL LIABILITY, ETC. (.4125 % x Total Job)		82,	000
SPECIAL TAXES, (Sales, Use, etc.) (4 % x Non. Proc. Matl.)		57,	000
TOTAL MATERIAL, SUBCONTRACTS & SHOP LABOR	11	904,	000
FIELD LABOR	2	575,	000
PAYROLL BURDEN 11.9%		305,	000
TOTAL FIELD LABOR	2	880,	000
FIELD SUPERVISION			
FIELD OFFICE PERSONNEL			
FIELD OFFICE EXPENSE 15 % x Labor and Burden		433,	000
FIELD COST ANALYSIS			
START-UP OPERATORS			
CONSTRUCTION EQUIPMENT AND TOOLS 12 % x Labor and Burden		347,	000
TOTAL OTHER FIELD CHARGES		780,	000
MECHANICAL ENGINEERING			
PROCESS ENGINEERING 12 %			
ESTIMATING AND COST ANALYSIS x	1	880,	000
HOME OFFICE TRAVEL EXPENSE Sub-Total			
PURCHASING, EXPEDITING AND SHOP INSPECTION Above			
ACCOUNTING, INDUSTRIAL REL., GEN. ADM. & CONSTRUCTION MANAGEMENT			
TOTAL HOME OFFICE EXPENSES	1	880,	000
SUB-TOTAL	17	444,	000
OVERHEAD 5%		872,	000
FEE			
TOTAL CHARGES	18	316,	000
CONTINGENCIES 10%	1	834,	000
ESCALATION			
GRAND TOTAL	20	150,	000

REMARKS

M A T E R I A L   S H E E T

ESTIMATE NO. 41940 (Task No. 11 - EPA 68-02-0241) DATE August 30, 1972 PAGE 2 OF 12

CUSTOMER Environmental Protection Agency LOCATION Site Undetermined

CODE	DESCRIPTION	SIZE		MATERIAL	LABOR	SUBCONTRACT
	Job Summary					
	Group I Limestone Handling Unit			74,890	66,550	76,000
	Group II Slurry Prep. Unit			667,340	145,570	46,300
	Group III Scrubbing System			2,455,410	990,460	1,600,000
	Group IV Flue Gas Disch. Unit			1,592,360	395,590	-
	Group V Reheat System			216,380	72,650	101,500
	Group VI Ammonia Unit			19,770	16,730	-
	Group VII Waste Disposal			412,270	453,870	3,694,000
	Group VIII Entrainment Separation	Recirc.		122,850	80,310	28,500
	Group IX Major Elect. Equip.			301,000	29,200	-
	Subtotal -	Groups I through IX		5,862,270	2,250,930	5,546,300
	Misc. Direct Charges: (4% and 10% x Labor)			88,730	221,070	-
	Constr. Supplies & Petty Tools	(6% x Labor)		133,000	-	-
	Testing Welders (.4% and 1.4% x Piping Labor)			2,700	10,000	-
	Temporary Constr. Facilities (6% x 4% x Labor)			132,000	93,000	-
	TOTAL MATERIAL, LABOR AND SUBCONTRACT			6,218,700	2,575,000	5,546,300

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CUSTOMER Environmental Protection Agency ESTIMATE NO. 41940

DATE August 30, 1972

LOCATION Site Undetermined

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CODE	DESCRIPTION	MATERIAL	LABOR	SUBCONTRACT
0100	FIRED HEATERS AND BOILERS	156,000	13,200	-
0200	BREECHING	930,000	100,000	-
0400	REACTORS AND INTERNALS			
0500	TOWERS AND INTERNALS			
0600	HEAT EXCHANGE EQUIPMENT			
0700	COOLING TOWERS			
0800	VESSELS, TANKS, DRUMS & INTERNALS	17,650	1,580	-
0900	PUMPS AND DRIVERS	207,760	42,370	-
1000	BLOWERS AND COMPRESSORS	344,500	26,640	-
1100	ELEVATORS, CONVEYORS, MATERIALS HANDLING EQUIP.	77,900	17,500	-
1200	MISCELLANEOUS MECHANICAL EQUIPMENT	623,200	58,400	-
2500	TANKAGE	100,000	10,000	579,300
2800	FILTERS, CENTRIFUGES, SEP. EQUIPMENT			
2900	AGITATORS AND MIXERS	84,300	2,350	-
3000	SCRUBBERS & ENTRAINMENT SEPARATORS	384,000	73,500	1,240,000
3100	MACHINE TOOLS & MACHINE SHOP EQUIPMENT			
3200	HEATING, VENTILATION, AIR CONDITIONING,			
	DUST CONTROL (Process only)			
3400	PACKAGE UNITS			
	SUB-TOTAL - MAJOR EQUIPMENT	2,925,310	345,540	1,819,300
1300	PIPING	1,573,200	721,700	-
1400	SEWERS Concrete Trenches	-	-	-
1500	INSTRUMENTATION	326,000	116,100	-
1600	ELECTRICAL	533,600	209,300	-
1700	CONCRETE 2,300 cy	72,940	314,040	-
1800	STRUCTURAL STEEL 570 tons	348,360	208,710	-
1900	FIREPROOFING			
2000	BUILDINGS			
2100	SITE DEVELOPMENT	-	-	3,727,000
2200	INSULATION	50,750	101,600	-
2300	PAINTING & PROTECTIVE COATINGS	23,230	93,680	-
2400	FIELD TESTING	4,480	39,660	-
2600	CHEMICALS AND CATALYST			
2700	PILING			
3300	FIRE PROTECTION	4,400	600	-
3500	MISCELLANEOUS FURNITURE FOR PLANT BUILDINGS			
	S U B - T O T A L	5,862,270	2,250,930	5,546,300
3700	MISCELLANEOUS DIRECT CHARGES (4% x 10% x Labor)	88,730	221,070	-
3800	STOREHOUSE ACCOUNTS			
3900	CONSTRUCTION SUPPLIES & PETTY TOOLS (6% x Labor)	133,000	-	-
1300	TESTING WELDERS (.4% x 1.4% x Piping Labor)	2,700	10,000	-
100 1600	TEMPORARY PIPING & ELECTRICAL FACILITIES (6%, 4%			
2000	TEMPORARY CONSTRUCTION BUILDINGS x	132,000	93,000	-
2100	TEMPORARY SITE DEVELOPMENT Labor)			
	T O T A L D I R E C T C O S T S	6,218,700	2,575,000	5,546,300

S U B - S U M M A R Y

CUSTOMER Environmental Protection Agency ESTIMATE NO. 41940 (Task No. 11)

LOCATION Durham, North Carolina DATE August 30, 1972

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CODE	DESCRIPTION	MATERIAL	LABOR	SUBCONTRACT
0100	FIRED HEATERS AND BOILERS			
0200	STACKS			
0400	REACTORS AND INTERNALS			
0500	TOWERS AND INTERNALS			
0600	HEAT EXCHANGE EQUIPMENT			
0700	COOLING TOWERS			
0800	VESSELS, TANKS, DRUMS & INTERNALS			
0900	PUMPS AND DRIVERS (1)	550	320	
1000	BLOWERS AND COMPRESSORS			
1100	ELEVATORS, CONVEYORS, MATERIALS HANDLING EQUIP. (2)	56,500	15,000	
1200	MISCELLANEOUS MECHANICAL EQUIPMENT			
2500	TANKAGE (1)			76,000
2800	FILTERS, CENTRIFUGES, SEP. EQUIPMENT			
2900	AGITATORS AND MIXERS			
3000	SCRUBBERS & ENTRAINMENT SEPARATORS			
3100	MACHINE TOOLS & MACHINE SHOP EQUIPMENT			
3200	HEATING, VENTILATION, AIR CONDITIONING, DUST CONTROL (Process only)			
3400	PACKAGE UNITS			
	SUB-TOTAL - MAJOR EQUIPMENT	57,050	15,320	76,000
1300	PIPING	200	600	
1400	SEWERS			
1500	INSTRUMENTATION			
1600	ELECTRICAL	8,500	8,100	
1700	CONCRETE 233 cy	8,400	39,200	
1800	STRUCTURAL STEEL	30	40	
1900	FIREPROOFING			
2000	BUILDINGS			
2100	SITE DEVELOPMENT			
2200	INSULATION	-	-	
2300	PAINTING & PROTECTIVE COATINGS	700	3,260	
2400	FIELD TESTING	10	30	
2600	CHEMICALS AND CATALYST			
2700	PILING			
3300	FIRE PROTECTION			
3500	MISCELLANEOUS FURNITURE FOR PLANT BUILDINGS			
	S U B - T O T A L	74,890	66,550	76,000
3700	MISCELLANEOUS DIRECT CHARGES			
3800	STOREHOUSE ACCOUNTS			
3900	CONSTRUCTION SUPPLIES & PETTY TOOLS			
1300	TESTING WELDERS			
1300 1600	TEMPORARY PIPING & ELECTRICAL FACILITIES			
2000	TEMPORARY CONSTRUCTION BUILDINGS			
2100	TEMPORARY SITE DEVELOPMENT			
	T O T A L D I R E C T C O S T S			

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CUSTOMER: Environmental Protection Agency ESTIMATE NO. 41940 (Task No. 11)

LOCATION: Durham, North Carolina DATE: August 30, 1972

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CODE	DESCRIPTION	MATERIAL	LABOR	SUBCONTRACT
0100	FIRED HEATERS AND BOILERS			
0200	STACKS			
0400	REACTORS AND INTERNALS			
0500	TOWERS AND INTERNALS			
0600	HEAT EXCHANGE EQUIPMENT			
0700	COOLING TOWERS			
0800	VESSELS, TANKS, DRUMS & INTERNALS (1)	1,500	150	
0900	PUMPS AND DRIVERS (4)	5,100	2,660	
1000	BLOWERS AND COMPRESSORS (1)	12,500	640	
1100	ELEVATORS, CONVEYORS, MATERIALS HANDLING EQUIP. (3)	21,400	2,500	
1200	MISCELLANEOUS MECHANICAL EQUIPMENT (3)	550,000	50,000	
2500	TANKAGE (1)			46,300
2800	FILTERS, CENTRIFUGES, SEP. EQUIPMENT			
2900	AGITATORS AND MIXERS (1)	26,900	500	
3000	SCRUBBERS & ENTRAINMENT SEPARATORS			
3100	MACHINE TOOLS & MACHINE SHOP EQUIPMENT			
3200	HEATING, VENTILATION, AIR CONDITIONING, DUST CONTROL (Process only)			
3400	PACKAGE UNITS			
	SUB-TOTAL - MAJOR EQUIPMENT	617,400	56,450	46,300
1300	PIPING	15,500	14,200	
1400	SEWERS			
1500	INSTRUMENTATION	6,000	2,000	
1600	ELECTRICAL	16,800	22,900	
1700	CONCRETE 244 cy	7,590	44,260	
1800	STRUCTURAL STEEL 4 ton	3,270	2,240	
1900	FIREPROOFING			
2000	BUILDINGS			
2100	SITE DEVELOPMENT			
2200	INSULATION	-	-	
2300	PAINTING & PROTECTIVE COATINGS	700	2,780	
2400	FIELD TESTING	80	740	
2600	CHEMICALS AND CATALYST			
2700	PILING			
3300	FIRE PROTECTION			
3500	MISCELLANEOUS FURNITURE FOR PLANT BUILDINGS			
	S U B - T O T A L	667,340	145,570	46,300
3700	MISCELLANEOUS DIRECT CHARGES			
3800	STOREHOUSE ACCOUNTS			
3900	CONSTRUCTION SUPPLIES & PETTY TOOLS			
1300	TESTING WELDERS			
100 1600	TEMPORARY PIPING & ELECTRICAL FACILITIES			
2000	TEMPORARY CONSTRUCTION BUILDINGS			
2100	TEMPORARY SITE DEVELOPMENT			
	T O T A L D I R E C T C O S T S			

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CUSTOMER: Environmental Protection Agency
ESTIMATE NO. 41940 (Task No. 11)

LOCATION: Durham, North Carolina
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CODE	DESCRIPTION	MATERIAL	LABOR	SUBCONTRACT
0100	FIRED HEATERS AND BOILERS			
0200	STACKS			
0400	REACTORS AND INTERNALS			
0500	TOWERS AND INTERNALS			
0600	HEAT EXCHANGE EQUIPMENT			
0700	COOLING TOWERS			
0800	VESSELS, TANKS, DRUMS & INTERNALS			
0900	PUMPS AND DRIVERS (20)	138,600	25,000	
1000	BLOWERS AND COMPRESSORS			
1100	ELEVATORS, CONVEYORS, MATERIALS HANDLING EQUIP.			
1200	MISCELLANEOUS MECHANICAL EQUIPMENT			
2500	TANKAGE (12)	100,000	10,000	360,000
2800	FILTERS, CENTRIFUGES, SEP. EQUIPMENT			
2900	AGITATORS AND MIXERS (8)	57,400	1,850	
3000	SCRUBBERS & ENTRAINMENT SEPARATORS (12)	384,000	73,500	1,240,000
3100	MACHINE TOOLS & MACHINE SHOP EQUIPMENT			
3200	HEATING, VENTILATION, AIR CONDITIONING, DUST CONTROL (Process only)			
3400	PACKAGE UNITS			
	SUB-TOTAL - MAJOR EQUIPMENT	680,000	110,350	1,600,000
1300	PIPING	1,218,700	404,100	
1400	SEWERS			
1500	INSTRUMENTATION	211,000	75,000	
1600	ELECTRICAL	115,600	115,800	
1700	CONCRETE 992 cy	30,570	107,900	
1800	STRUCTURAL STEEL 324 ton	184,350	106,100	
1900	FIREPROOFING			
2000	BUILDINGS			
2100	SITE DEVELOPMENT			
2200	INSULATION	1,300	2,700	
2300	PAINTING & PROTECTIVE COATINGS	11,390	46,010	
2400	FIELD TESTING	2,500	22,500	
2600	CHEMICALS AND CATALYST			
2700	PILING			
3300	FIRE PROTECTION			
3500	MISCELLANEOUS FURNITURE FOR PLANT BUILDINGS			
	S U B - T O T A L	2,455,410	990,460	1,600,000
3700	MISCELLANEOUS DIRECT CHARGES			
3800	STOREHOUSE ACCOUNTS			
3900	CONSTRUCTION SUPPLIES & PETTY TOOLS			
1300	TESTING WELDERS			
100 1600	TEMPORARY PIPING & ELECTRICAL FACILITIES			
2000	TEMPORARY CONSTRUCTION BUILDINGS			
2100	TEMPORARY SITE DEVELOPMENT			
	T O T A L D I R E C T C O S T S			

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CUSTOMER Environmental Protection Agency

ESTIMATE NO. 41940 (Task No. 11)

LOCATION Durham, North Carolina

DATE August 30, 1972

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CODE	DESCRIPTION	MATERIAL	LABOR	SUBCONTRACT
0100	FIRED HEATERS AND BOILERS			
0200	~~STACKS~~ Breeching	930,000	100,000	
0400	REACTORS AND INTERNALS			
0500	TOWERS AND INTERNALS			
0600	HEAT EXCHANGE EQUIPMENT			
0700	COOLING TOWERS			
0800	VESSELS, TANKS, DRUMS & INTERNALS			
0900	PUMPS AND DRIVERS			
1000	BLOWERS AND COMPRESSORS (4)	332,000	26,000	
1100	ELEVATORS, CONVEYORS, MATERIALS HANDLING EQUIP.			
1200	MISCELLANEOUS MECHANICAL EQUIPMENT (16)	73,200	8,400	
2500	TANKAGE			
2800	FILTERS, CENTRIFUGES, SEP. EQUIPMENT			
2900	AGITATORS AND MIXERS			
3000	SCRUBBERS & ENTRAINMENT SEPARATORS			
3100	MACHINE TOOLS & MACHINE SHOP EQUIPMENT			
3200	HEATING, VENTILATION, AIR CONDITIONING, DUST CONTROL (Process only)			
3400	PACKAGE UNITS			
	SUB-TOTAL - MAJOR EQUIPMENT	1,335,200	134,400	-
1300	PIPING Minor Util. Piping Only	(Included with Group III Piping)		
1400	SEWERS			
1500	INSTRUMENTATION	62,000	22,000	
1600	ELECTRICAL	15,000	15,600	
1700	CONCRETE 381 cy	12,250	66,200	
1800	STRUCTURAL STEEL 200 ton	117,450	49,950	
1900	FIREPROOFING			
2000	BUILDINGS			
2100	SITE DEVELOPMENT			
2200	INSULATION	47,200	94,400	
2300	PAINTING & PROTECTIVE COATINGS	3,260	13,040	
2400	FIELD TESTING	-	-	
2600	CHEMICALS AND CATALYST			
2700	PILING			
3300	FIRE PROTECTION			
3500	MISCELLANEOUS FURNITURE FOR PLANT BUILDINGS			
	S U B - T O T A L	1,592,360	395,590	-
3700	MISCELLANEOUS DIRECT CHARGES			
3800	STOREHOUSE ACCOUNTS			
3900	CONSTRUCTION SUPPLIES & PETTY TOOLS			
1300	TESTING WELDERS			
100 1600	TEMPORARY PIPING & ELECTRICAL FACILITIES			
2000	TEMPORARY CONSTRUCTION BUILDINGS			
2100	TEMPORARY SITE DEVELOPMENT			
	T O T A L D I R E C T C O S T S			

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CUSTOMER Environmental Protection Agency ESTIMATE NO. 41940 (Task No. 11)

LOCATION Duham, North Carolina DATE August 30, 1972

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CODE	DESCRIPTION	MATERIAL	LABOR	SUBCONTRACT
0100	FIRED HEATERS AND BOILERS (4)	156,000	13,200	
0200	STACKS			
0400	REACTORS AND INTERNALS			
0500	TOWERS AND INTERNALS			
0600	HEAT EXCHANGE EQUIPMENT			
0700	COOLING TOWERS			
0800	VESSELS, TANKS, DRUMS & INTERNALS			
0900	PUMPS AND DRIVERS (5)	770	370	
1000	BLOWERS AND COMPRESSORS			
1100	ELEVATORS, CONVEYORS, MATERIALS HANDLING EQUIP.			
1200	MISCELLANEOUS MECHANICAL EQUIPMENT			
2500	TANKAGE (1)			68,500
2800	FILTERS, CENTRIFUGES, SEP. EQUIPMENT			
2900	AGITATORS AND MIXERS			
3000	SCRUBBERS & ENTRAINMENT SEPARATORS			
3100	MACHINE TOOLS & MACHINE SHOP EQUIPMENT			
3200	HEATING, VENTILATION, AIR CONDITIONING, DUST CONTROL (Process only)			
3400	PACKAGE UNITS			
	SUB-TOTAL - MAJOR EQUIPMENT	156,770	13,570	68,500
1300	PIPING	5,500	16,200	
1400	SEWERS			
1500	INSTRUMENTATION	36,000	13,000	
1600	ELECTRICAL	8,800	15,200	
1700	CONCRETE 45 cy	1,400	7,640	
1800	STRUCTURAL STEEL	2,280	1,340	
1900	FIREPROOFING			
2000	BUILDINGS			
2100	SITE DEVELOPMENT			33,000
2200	INSULATION	–	–	
2300	PAINTING & PROTECTIVE COATINGS	1,070	4,280	
2400	FIELD TESTING	160	820	
2600	CHEMICALS AND CATALYST			
2700	PILING			
3300	FIRE PROTECTION	4,400	600	
3500	MISCELLANEOUS FURNITURE FOR PLANT BUILDINGS			
	S U B - T O T A L	216,380	72,650	101,500
3700	MISCELLANEOUS DIRECT CHARGES			
3800	STOREHOUSE ACCOUNTS			
3900	CONSTRUCTION SUPPLIES & PETTY TOOLS			
1300	TESTING WELDERS			
1300 1600	TEMPORARY PIPING & ELECTRICAL FACILITIES			
2000	TEMPORARY CONSTRUCTION BUILDINGS			
2100	TEMPORARY SITE DEVELOPMENT			
	T O T A L D I R E C T C O S T S			

S U B - S U M M A R Y

CUSTOMER Environmental Protection Agency

ESTIMATE NO.

LOCATION Durham, North Carolina

DATE August 30, 1972

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CODE	DESCRIPTION	MATERIAL	LABOR	SUBCONTRACT
0100	FIRED HEATERS AND BOILERS			
0200	STACKS			
0400	REACTORS AND INTERNALS			
0500	TOWERS AND INTERNALS			
0600	HEAT EXCHANGE EQUIPMENT			
0700	COOLING TOWERS			
0800	VESSELS, TANKS, DRUMS & INTERNALS (1)	10,000	750	
0900	PUMPS AND DRIVERS			
1000	BLOWERS AND COMPRESSORS			
1100	ELEVATORS, CONVEYORS, MATERIALS HANDLING EQUIP.			
1200	MISCELLANEOUS MECHANICAL EQUIPMENT			
2500	TANKAGE			
2800	FILTERS, CENTRIFUGES, SEP. EQUIPMENT			
2900	AGITATORS AND MIXERS			
3000	SCRUBBERS & ENTRAINMENT SEPARATORS			
3100	MACHINE TOOLS & MACHINE SHOP EQUIPMENT			
3200	HEATING, VENTILATION, AIR CONDITIONING, DUST CONTROL (Process only)			
3400	PACKAGE UNITS			
	SUB-TOTAL - MAJOR EQUIPMENT	10,000	750	-
1300	PIPING	1,400	5,100	
1400	SEWERS			
1500	INSTRUMENTATION	2,800	1,000	
1600	ELECTRICAL	2,300	2,100	
1700	CONCRETE 20 cy	680	2,250	
1800	STRUCTURAL STEEL	180	240	
1900	FIREPROOFING			
2000	BUILDINGS			
2100	SITE DEVELOPMENT			
2200	INSULATION	2,250	4,500	
2300	PAINTING & PROTECTIVE COATINGS	130	520	
2400	FIELD TESTING	30	270	
2600	CHEMICALS AND CATALYST			
2700	PILING			
3300	FIRE PROTECTION			
3500	MISCELLANEOUS FURNITURE FOR PLANT BUILDINGS			
	S U B - T O T A L	19,770	16,730	-
3700	MISCELLANEOUS DIRECT CHARGES			
3800	STOREHOUSE ACCOUNTS			
3900	CONSTRUCTION SUPPLIES & PETTY TOOLS			
1300	TESTING WELDERS			
1300 1600	TEMPORARY PIPING & ELECTRICAL FACILITIES			
2000	TEMPORARY CONSTRUCTION BUILDINGS			
2100	TEMPORARY SITE DEVELOPMENT			
	T O T A L D I R E C T C O S T S			

S U B - S U M M A R Y

CUSTOMER Environmental Protection Agency

ESTIMATE NO 41940 (Task No. 11)

LOCATION Durham, North Carolina

DATE August 30, 1972

PAGE 10 OF 12

CODE	DESCRIPTION	MATERIAL	LABOR	SUBCONTRACT
0100	FIRED HEATERS AND BOILERS			
0200	STACKS			
0400	REACTORS AND INTERNALS			
0500	TOWERS AND INTERNALS			
0600	HEAT EXCHANGE EQUIPMENT			
0700	COOLING TOWERS			
0800	VESSELS, TANKS, DRUMS & INTERNALS (2)	6,150	680	
0900	PUMPS AND DRIVERS (7)	31,840	7,020	
1000	BLOWERS AND COMPRESSORS			
1100	ELEVATORS, CONVEYORS, MATERIALS HANDLING EQUIP.			
1200	MISCELLANEOUS MECHANICAL EQUIPMENT			
2500	TANKAGE			
2800	FILTERS, CENTRIFUGES, SEP. EQUIPMENT			
2900	AGITATORS AND MIXERS			
3000	SCRUBBERS & ENTRAINMENT SEPARATORS			
3100	MACHINE TOOLS & MACHINE SHOP EQUIPMENT			
3200	HEATING, VENTILATION, AIR CONDITIONING, DUST CONTROL (Process only)			
3400	PACKAGE UNITS			
	SUB-TOTAL - MAJOR EQUIPMENT	37,990	7,700	-
1300	PIPING	251,700	232,000	
1400	SEWERS			
1500	INSTRUMENTATION	5,300	2,000	
1600	ELECTRICAL	66,400	109,300	
1700	CONCRETE 193 cy	5,690	24,030	
1800	STRUCTURAL STEEL 34 ton	38,700	45,900	
1900	FIREPROOFING			
2000	BUILDINGS			
2100	SITE DEVELOPMENT	-	-	3,694,000
2200	INSULATION	-	-	-
2300	PAINTING & PROTECTIVE COATINGS	5,090	20,340	
2400	FIELD TESTING	1,400	12,600	
2600	CHEMICALS AND CATALYST			
2700	PILING			
3300	FIRE PROTECTION			
3500	MISCELLANEOUS FURNITURE FOR PLANT BUILDINGS			
	S U B - T O T A L	412,270	453,870	3,694,000
3700	MISCELLANEOUS DIRECT CHARGES			
3800	STOREHOUSE ACCOUNTS			
3900	CONSTRUCTION SUPPLIES & PETTY TOOLS			
1300	TESTING WELDERS			
100 1600	TEMPORARY PIPING & ELECTRICAL FACILITIES			
2000	TEMPORARY CONSTRUCTION BUILDINGS			
2100	TEMPORARY SITE DEVELOPMENT			
	T O T A L D I R E C T C O S T S			

S U B - S U M M A R Y

CUSTOMER Environmental Protection Agency

LOCATION Durham, North Carolina

ESTIMATE NO. 41940 (Task No. 11)

DATE August 30, 1972

PAGE 11 OF 12

CODE	DESCRIPTION	MATERIAL	LABOR	SUBCONTRACT
0100	FIRED HEATERS AND BOILERS			
0200	STACKS			
0400	REACTORS AND INTERNALS			
0500	TOWERS AND INTERNALS			
0600	HEAT EXCHANGE EQUIPMENT			
0700	COOLING TOWERS			
0800	VESSELS, TANKS, DRUMS & INTERNALS			
0900	PUMPS AND DRIVERS (5)	30,900	7,000	
1000	BLOWERS AND COMPRESSORS			
1100	ELEVATORS, CONVEYORS, MATERIALS HANDLING EQUIP.			
1200	MISCELLANEOUS MECHANICAL EQUIPMENT			
2500	TANKAGE (1)	-	-	28,500
2800	FILTERS, CENTRIFUGES, SEP. EQUIPMENT			
2900	AGITATORS AND MIXERS			
3000	SCRUBBERS & ENTRAINMENT SEPARATORS			
3100	MACHINE TOOLS & MACHINE SHOP EQUIPMENT			
3200	HEATING, VENTILATION, AIR CONDITIONING, DUST CONTROL (Process only)			
3400	PACKAGE UNITS			
	SUB-TOTAL - MAJOR EQUIPMENT	30,900	7,000	28,500
1300	PIPING	80,200	49,500	
1400	SEWERS			
1500	INSTRUMENTATION	2,900	1,100	
1600	ELECTRICAL	3,200	5,300	
1700	CONCRETE 80 cy	2,660	9,560	
1800	STRUCTURAL STEEL	2,100	2,900	
1900	FIREPROOFING			
2000	BUILDINGS			
2100	SITE DEVELOPMENT			
2200	INSULATION	-	-	
2300	PAINTING & PROTECTIVE COATINGS	590	2,250	
2400	FIELD TESTING	300	2,700	
2600	CHEMICALS AND CATALYST			
2700	PILING			
3300	FIRE PROTECTION			
3500	MISCELLANEOUS FURNITURE FOR PLANT BUILDINGS			
	S U B - T O T A L	122,850	80,310	28,500
3700	MISCELLANEOUS DIRECT CHARGES			
3800	STOREHOUSE ACCOUNTS			
3900	CONSTRUCTION SUPPLIES & PETTY TOOLS			
1300	TESTING WELDERS			
100 1600	TEMPORARY PIPING & ELECTRICAL FACILITIES			
2000	TEMPORARY CONSTRUCTION BUILDINGS			
2100	TEMPORARY SITE DEVELOPMENT			
	T O T A L D I R E C T C O S T S			

S U B - S U M M A R Y

CUSTOMER Environmental Protection Agency ESTIMATE NO. 41940 (Task No. 11)

LOCATION Durham, North Carolina DATE August 30, 1972

PAGE 12 OF 12

CODE	DESCRIPTION	MATERIAL	LABOR	SUBCONTRACT
0100	FIRED HEATERS AND BOILERS			
0200	STACKS			
0400	REACTORS AND INTERNALS			
0500	TOWERS AND INTERNALS			
0600	HEAT EXCHANGE EQUIPMENT			
0700	COOLING TOWERS			
0800	VESSELS, TANKS, DRUMS & INTERNALS			
0900	PUMPS AND DRIVERS			
1000	BLOWERS AND COMPRESSORS			
1100	ELEVATORS, CONVEYORS, MATERIALS HANDLING EQUIP.			
1200	MISCELLANEOUS MECHANICAL EQUIPMENT			
2500	TANKAGE			
2800	FILTERS, CENTRIFUGES, SEP. EQUIPMENT			
2900	AGITATORS AND MIXERS			
3000	SCRUBBERS & ENTRAINMENT SEPARATORS			
3100	MACHINE TOOLS & MACHINE SHOP EQUIPMENT			
3200	HEATING, VENTILATION, AIR CONDITIONING, DUST CONTROL (Process only)			
3400	PACKAGE UNITS			
	SUB-TOTAL - MAJOR EQUIPMENT	-	-	-
1300	PIPING			
1400	SEWERS			
1500	INSTRUMENTATION			
1600	ELECTRICAL	297,000	15,000	
1700	CONCRETE 130 cy	3,700	13,000	
1800	STRUCTURAL STEEL			
1900	FIREPROOFING			
2000	BUILDINGS			
2100	SITE DEVELOPMENT			
2200	INSULATION			
2300	PAINTING & PROTECTIVE COATINGS	300	1,200	
2400	FIELD TESTING			
2600	CHEMICALS AND CATALYST			
2700	PILING			
3300	FIRE PROTECTION			
3500	MISCELLANEOUS FURNITURE FOR PLANT BUILDINGS			
	S U B - T O T A L	301,000	29,200	-
3700	MISCELLANEOUS DIRECT CHARGES			
3800	STOREHOUSE ACCOUNTS			
3900	CONSTRUCTION SUPPLIES & PETTY TOOLS			
1300	TESTING WELDERS			
100 1600	TEMPORARY PIPING & ELECTRICAL FACILITIES			
2000	TEMPORARY CONSTRUCTION BUILDINGS			
2100	TEMPORARY SITE DEVELOPMENT			
	T O T A L D I R E C T C O S T S			

Appendix 2

Annual Operating Cost

ANNUAL OPERATING COST

WET LIMESTONE SCRUBBING

Client: Environmental Protection Agency
Process: Wet Limestone Scrubbing
Plant Size: 500 MW
Fixed Capital Investment: $20,150,000
Stream Hours: 7,000 Hrs/Yr.

I.	Raw Material	Quantity	Unit Cost	Annual Cost
	A. Limestone	31.9 TPH	4.00 $/T	$ 893,200
	B. Ammonia	1,375 Lbs/Day	50.00 $/T	10,030
II.	Utilities	Quantity	Unit Cost	Annual Cost
	A. Water, Process	400 gpm	$0.20/M Gal.	$ 33,600
	B. Electricity	11,300 KW	6.75 Mils/KWH	533,740
	C. Fuel (No. 2 Oil)	95.2 MM BTU/Hr.	$.80/MM BTU	533,120
III.	Operating Labor		Rate	Annual Cost
	A. Direct Labor	(2 Men/Shift)	4.50 $/Hr.	$ 78,840
	B. Supervision		15% Operating Labor	11,830
IV.	Maintenance		Rate	Annual Cost
	A. Labor and Materials		4.0% Fixed Investment	$ 806,000
	B. Supplies		15% Labor & Materials	120,900
V.	Overhead		Rate	Annual Cost
	A. Plant		50% Operating & Maintenance	$ 508,785
	B. Payroll		20% Operating	18,130
VI.	Fixed Cost		Rate	Annual Cost
	(Depreciation, Interim Replacement,) (Insurance, Taxes, Cost of Capital)		18.22% Fixed Investment	$3,671,330

Cost of Capital 8%
Depreciation 15 Years Sinking Fund Method
Insurance .25%
Interim Replacement 0.35%
Taxes 3.16% Federal, 2.33% Local

VII.	Total Annual Cost	$7,219,505
	A. Mills/KWH	2.06

WET LIMESTONE SCRUBBING

Allocation of Annual Raw Material and Utilities Cost by Groups

Group	Item	Units	$ Per Year	Group Cost $ Per Year	Per Cent
1	Electricity	31 kw	1,463	1,463	0.1
2	Limestone	223,300 tons	893,200		
	Water	9,383 M gal	1,882		
	Electricity	1,437 kw	67,900	962,982	55.5
3	Ammonia	200.6 tons	10,030		
	Electricity	1,863 kw	87,990	98,020	5.6
4	Electricity	6,700 kw	316,470	316,470	18.3
5	Fuel Oil	666,400 MM Btu	533,120		
	Electricity	67 kw	3,162	536,282	15.5
6	-	-	-	-	-
7	Electricity	373 kw	17,601	17,601	1.0
8	Electricity	829 kw	39,154		
	Water	158.6 MM gal	31,718	70,872	4.0
				2,003,690	100.0

NOTE:

Group numbers correspond to groups of process equipment used in the capital cost estimate.

Appendix 3

Drawings

Process Flow Diagram - Drawing No. A-202, Sheet 1

Process Flow Diagram - Drawing No. A-202, Sheet 2

Equipment Arrangement - Drawing No. A-601, Sheet 1

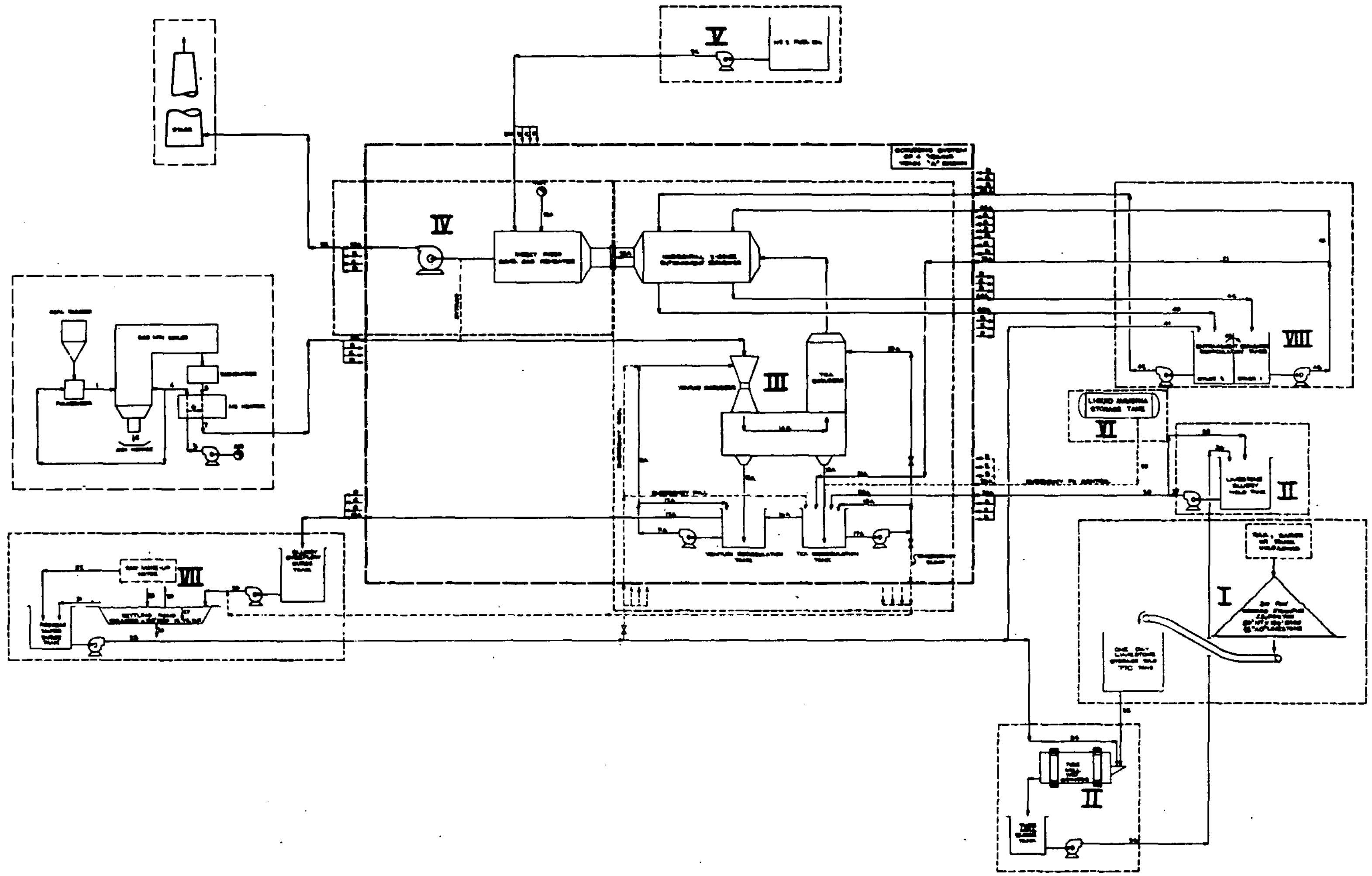
Equipment Arrangement - Drawing No. A-601, Sheet 2

Equipment Arrangement - Drawing No. A-601, Sheet 3

Piping Layout - Drawing No. A-801, Sheet 1

Piping Layout - Drawing No. A-801, Sheet 2

Piping Layout - Drawing No. A-801, Sheet 3



LIMESTONE SLURRY SCRUBBING SYSTEM
FOR NEW 500 MW BOILER

DWG. NO. A-202 SHEET 1 OF 2

PROCESS FLOW SHEET - MATERIAL BALANCE

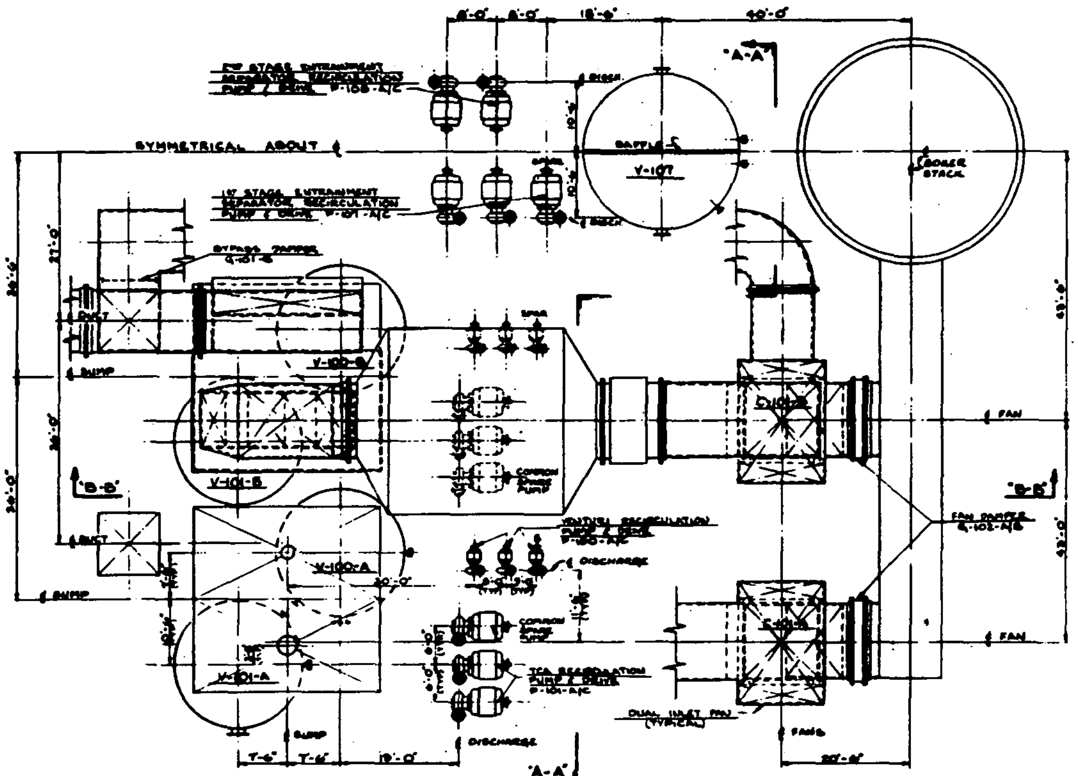
DWG. NO. A-202 SHEET 2 of 2

	Stream No.	Units: Gas	Units: Solid or Liquid	No.	1	2	3	4	5	6	7	8A, 8B 8C & 8D	9A, 9B 9C & 9D	10A, 10B 10C & 10D	11A, 11B 11C & 11D	12A, 12B 12C & 12D	13A, 13B 13C & 13D
	Title				Coal	Ash Slag	Air to Air Heater	Air to Boiler	Comb. Gas to Air Heater	Air Heater Leakage	Comb. Gas to Scrubbing System	Comb. Gas to a Scrubbing Train	Slurry to a Venturi Scrubber	Slurry from a Venturi Scrubber	Tot. Slurry from a Venturi Scrubber	Recycle Slurry to a Venturi Recirc. Tk.	Slurry O.F. from a Venturi Recir. Tk.
1	Total Rate	10^3 lb/hr	10^3 lb/hr	1	377	14	4,611	4,023	4,353	579	4,932	233	2,570	2,528	2,910	336	164
2	Total Rate	10^3 SCFM	GPM	2			951	823	875	119	998	249	4,589	4,480	5,189	600	293
3	Water Rate	10^3 lb/hr	GPM	3							232	60	4,150	4,060	4,494	544	266
4	Solids Rate	10^3 lb/hr	10^3 lb/hr	4	95.2		0	0	40.8	0	40.8	10.2	488	498	552	64	31
5	Solids Conc.	GR/SCF	% Solids	5			0	0		0	5.56	5.56	19.0	19.7	19.0	19.0	19.0
6	Temperature	°F	°F	6			40 - 80	600	775	40 - 80	300	300	114 - 127	114 - 127	114 - 127	114 - 127	114 - 127
7	Density		S.G.	7									1.12	1.13	1.12	1.12	1.12
8	Viscosity @ 100°F		CPS	8													
9	Ph		Ph	9													
10	SO_2 Rate	10^3 lb/hr		10			0	0	25.0	0	25.0	6.25					

	Stream No.	Units: Gas	Units: Solid or Liquid	No.	14A, 14B 14C & 14D	15A, 15B 15C & 15D	16A, 16B 16C & 16D	17A, 17B 17C & 17D	18A, 18B 18C & 18D	19A, 19B 19C & 19D	20A, 20B 20C & 20D	21	21A, 21B 21C & 21D	22A, 22B 22C & 22D	23A, 23B 23C & 23D	24	24A, 24B 24C & 24D	25
	Title				Comb. Gas from a Venturi Scrubber	Slurry from a TCA Scrubber	Overflow from a TCA Recirc. Tk.	Tot. Slurry from a TCA Recirc. Tk.	Recycle Slurry to a TCA Recirc. Tk.	Slurry to a TCA Scrubber	L.S. Slurry to a Recirc. Tank	E.S. Water to Scrubbing System	E.S. Water to a TCA Recirc. Tank	Comb. Gas from an Entr. Separ.	Air to a Comb. Gas Reheater	Oil to Scrubbing System	Oil to a Comb. Gas Reheater	Comb. Gas from Scrubbing System
1	Total Rate	10^3 lb/hr	10^3 lb/hr	1	1,280	5,562	205	5,878	318	5,560	25.9	708	177	1,280	24.6	6.8	1.7 (3)	5,260
2	Total Rate	10^3 SCFM	GPM	2	263	10,500	386	11,100	600	10,500	32.2	1,420	355	263	5.1	16.0	4.0	1,080
3	Water Rate	10^3 lb/hr	GPM	3	110	10,000	370	10,672	572	10,100	21.2	1,420	355	111	0.3	0	0	444
4	Solids Rate	10^3 lb/hr	10^3 lb/hr	4	0.0412	564	21	588	32	556	15.9		0	1	0	0	0	4
5	Solids Conc.	GR/SCF	% Solids	5	0.021	10.2	10	10	10	10	60		0	0.06	0	0	0	0.06
6	Temperature	°F	°F	6	114 - 127	114 - 127	114 - 127	114 - 127	114 - 127	114 - 127	40 - 80	114 - 127	114 - 127	114 - 127	40 - 80	40 - 80	40 - 80	200
7	Density		S.G.	7		1.06	1.06	1.06	1.06	1.06	1.61	1.0	1.0			0.87	0.87	
8	Viscosity @ 100°F		CPS	8								0.68	0.68			2.78	2.78	
9	Ph		Ph	9		5.8 - 6.0	5.8 - 6.0	5.8 - 6.0	5.8 - 6.0	5.8 - 6.0								
10	SO_2 Rate	10^3 lb/hr		10	485									1.06	0			4.28

	Stream No.	Units: Gas	Units: Solid or Liquid	No.	25A, 25B 25C & 25D	26	27	28	29	30	31	32	33	34	35	36	37	38	39
	Title				Comb. Gas from a Comb. Gas Reheater	Slurry Overflow	Pond Solids Accum.	Pond Precip. Gain	Pond Evap. Loss	Pond Seepage Loss	Pond Process Water Overflow	Raw Make-up Water	Total Process Water	Process Water to Tube Mill	Limestone to Tube Mill	Slurry to L.S. Hold Tank	Total Slurry from L.S. Hold Tank	Recycle Slurry to L.S. Hold Tank	Emerg'cy Ammonia to Scrubb. System
1	Total Rate	10^3 lb/hr	10^3 lb/hr	1	1,315	656	124	298	184	74	572	198	770	42	63.7	104	178	282	6.0
2	Total Rate	10^3 SCFM	GPM	2	270	1,170	110	595	368	148	1,139	396	1,540	84	(31.9 TPH)	129	221	330	22.6
3	Water Rate	10^3 lb/hr	GPM	3	111	1,060	0	595	368	148	1,139	396	1,540	84	0	84.9	142	227	
4	Solids Rate	10^3 lb/hr	10^3 lb/hr	4	1	124	124	0			0	0	0	0	63.7	63.7	106	170	
5	Solids Conc.	GR/SCF	% Solids	5	0.06	19.0	100 (40)	0			0	0	0	0	100	60	60	60	
6	Temperature	°F	°F	6	200	114 - 127	40 - 80	40 - 80		40 - 80	40 - 80	40 - 80	40 - 80	40 - 80	40 - 80	40 - 80	40 - 80	40 - 80	100
7	Density		S.G.	7		1.12		1.0		1.0	1.0	1.0	1.0	1.0	2.7	1.61	1.61	1.61	
8	Viscosity @ 100°F		CPS	8															
9	Ph		Ph	9				7.0				7.0	7.0	7.0					
10	SO_2 Rate	10^3 lb/hr		10	1.07														

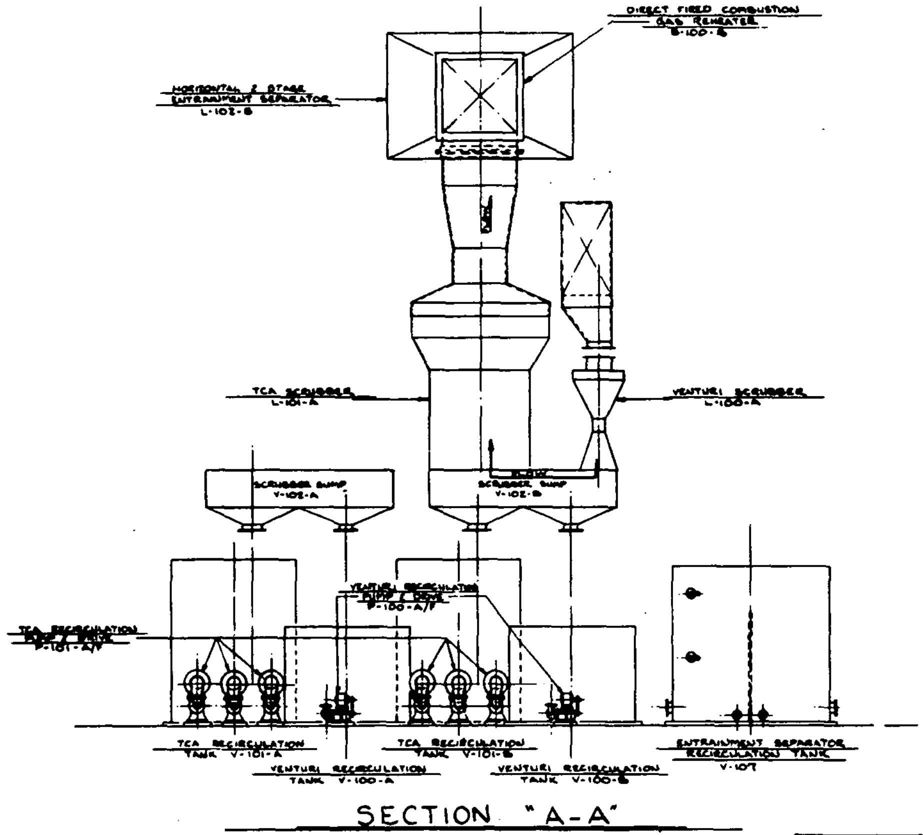
	Stream No.	Units: Gas	Units: Solid or Liquid	No.	39A, 39B, 39C & 39D	40	40A, 40B 40C & 40D	41	42	42A, 42B 42C & 42D	43	44	44A, 44B 44C & 44D	45	46	46A, 46B 46C & 46D
	Title				Emerg'cy Ammonia to a TCA Recirc. Tk.	Overflow from E.S.'s Tot. Rec. Tk. Stage 2	Overflow from an E.S. Stage 2	Process Water to E.S. Rec. Tk. Stage 2	Overflow from E.S. Rec. Tank Stage 2	Wash Water to an E.S. Stage 2	Overflow from E.S. Rec. Tank Stage 2	Overflow from E.S. to Rec. Tk. Stage 1	Overflow from an E.S. Stage 1	Tot. O/flow from E.S. Rec. Tank Stage 1	Total Wash Water to E.S. Stage 1	Wash Water to an E.S. Stage 1
1	Total Rate	10^3 lb/hr	10^3 lb/hr	1	1.5	6,560	1,640	708	6,560	1,640	708	6,560	1,640	7,268	6,560	1,640
2	Total Rate	10^3 SCFM	GPM	2		13,100	3,270	1,420	13,100	3,270	1,420	13,100	3,270	14,420	13,100	3,270
3	Water Rate	10^3 lb/hr	GPM	3		13,100	3,270	1,420	13,100	3,270	1,420	13,100	3,270	14,420	13,100	3,270
4	Solids Rate	10^3 lb/hr	10^3 lb/hr	4		0	0	0	0	0	0	0	0	0	0	0
5	Solids Conc.	GR/SCF	% Solids	5		0	0	0	0	0	0	0	0	0	0	0
6	Temperature	°F	°F	6	100	114 - 127	114 - 127	40 - 80	114 - 127	114 - 127	40 - 80	114 - 127	114 - 127	114 - 127	114 - 127	114 - 127
7	Density		S.G.	7		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
8	Viscosity @ 100°F		CPS	8		0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
9	Ph		Ph	9												
10	SO_2 Rate	10^3 lb/hr		10												



PLAN

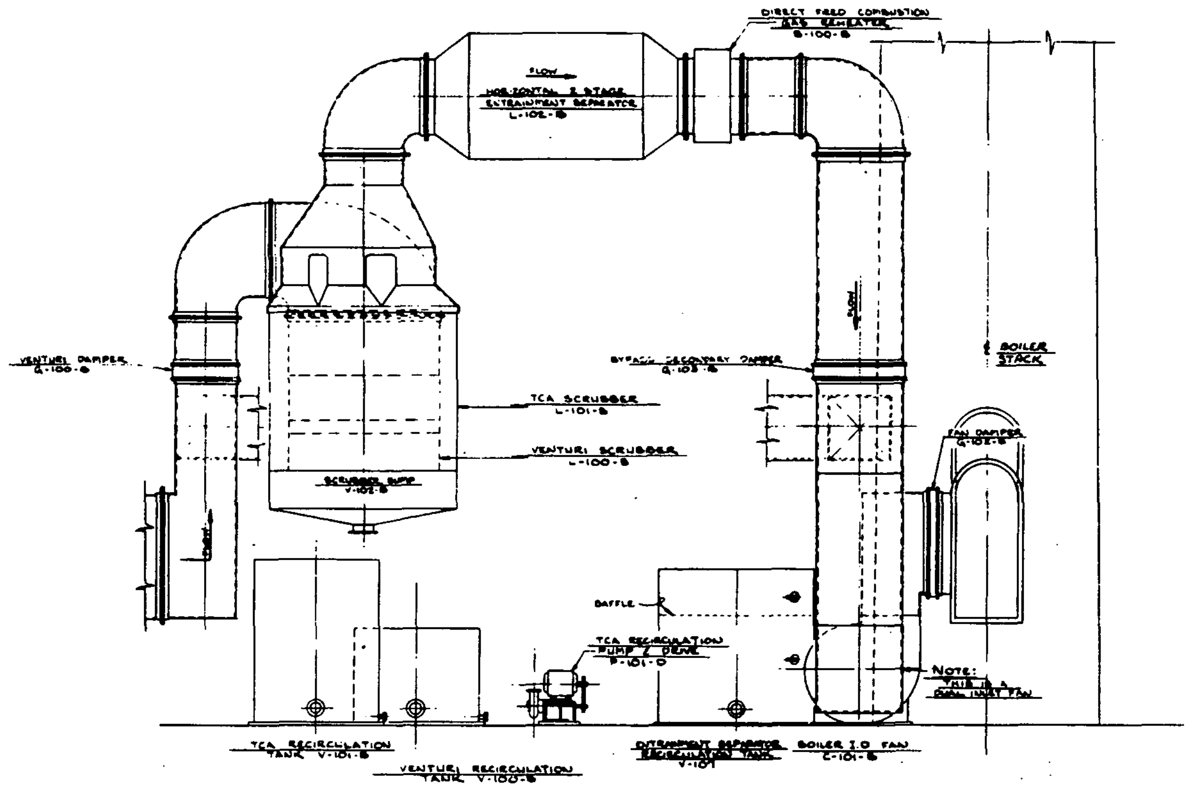
LIMESTONE SLURRY SCRUBBING SYSTEM
FOR NEW 500 MW BOILER

DWG. NO. A-601 SHEET 1 of 3



LIMESTONE SLURRY SCRUBBING SYSTEM FOR NEW 500 MW BOILER

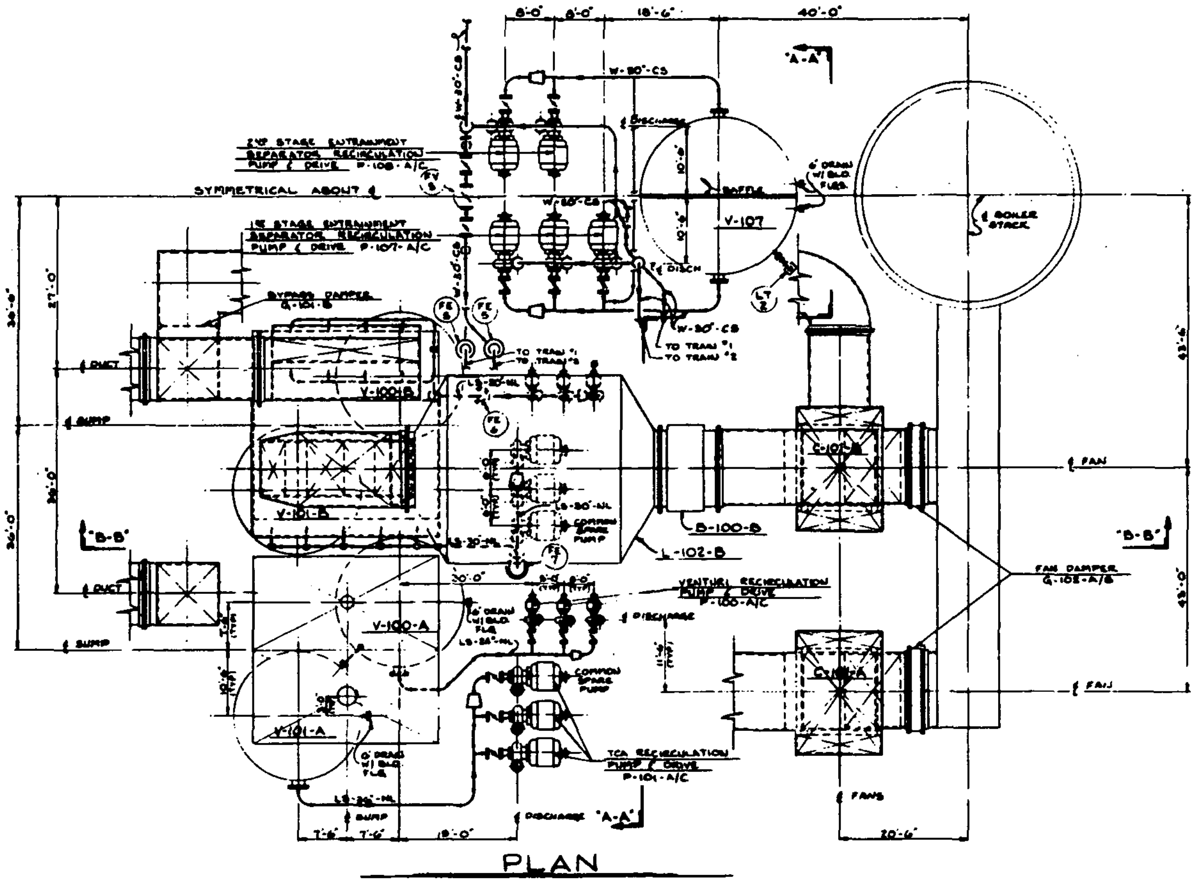
DWG. NO. A-601 SHEET 2 of 3



SECTION "B-B"

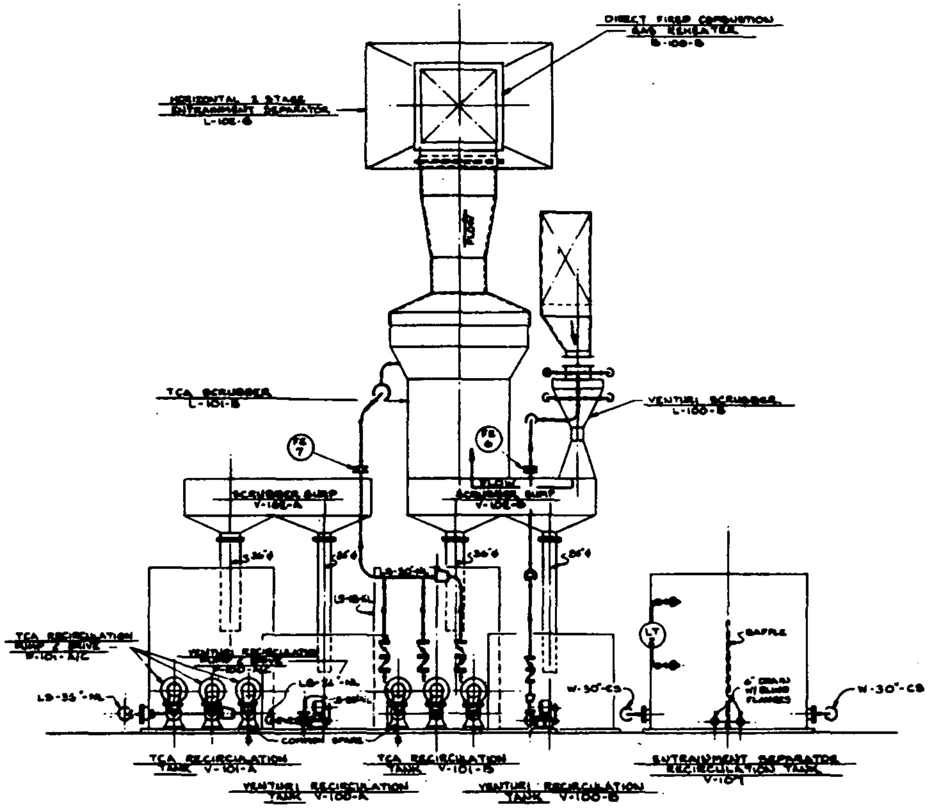
LIMESTONE SLURRY SCRUBBING SYSTEM
FOR NEW 500 MW BOILER

DWG. NO. A-601 SHEET 3 of 3



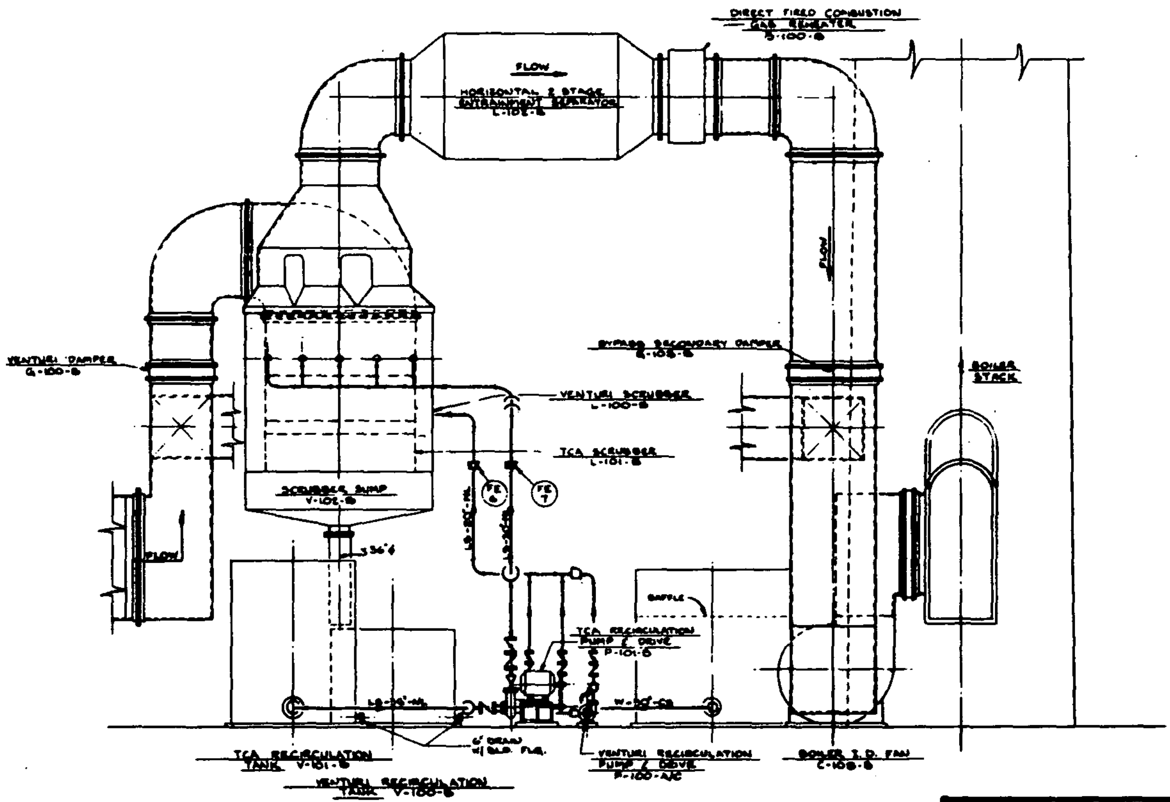
LIMESTONE SLURRY SCRUBBING SYSTEM
FOR NEW 500 MW BOILER

DWG. NO. A-801 SHEET 1 of 3



SECTION "A-A"

LIMESTONE SLURRY SCRUBBING SYSTEM FOR NEW 500 MW BOILER
DWG. NO. A-801 SHEET 2 of 3



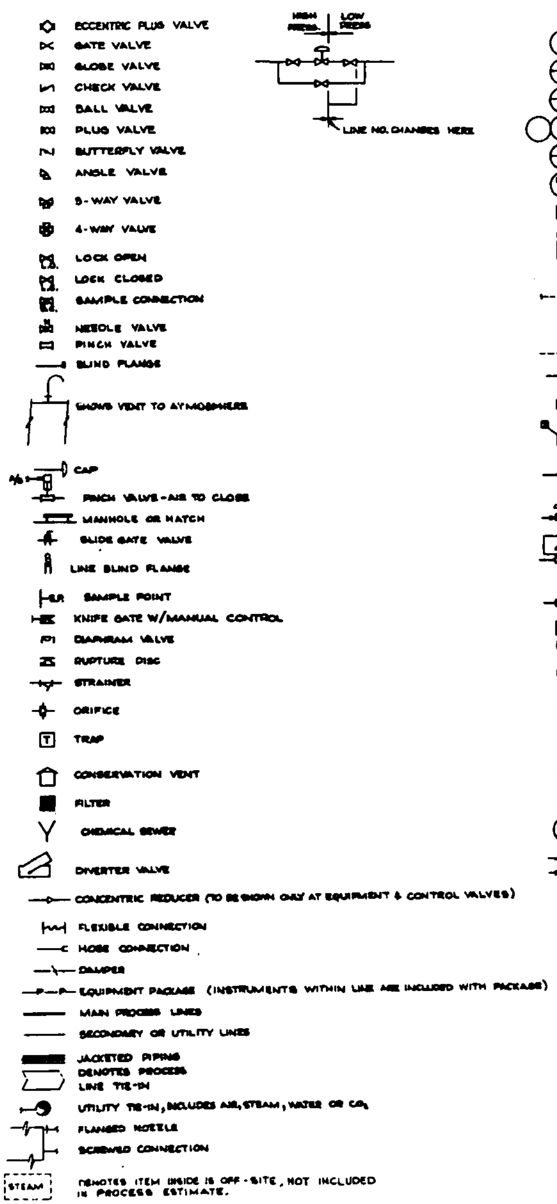
SECTION 'B-B'

LIMESTONE SLURRY SCRUBBING SYSTEM FOR NEW 500 MW BOILER

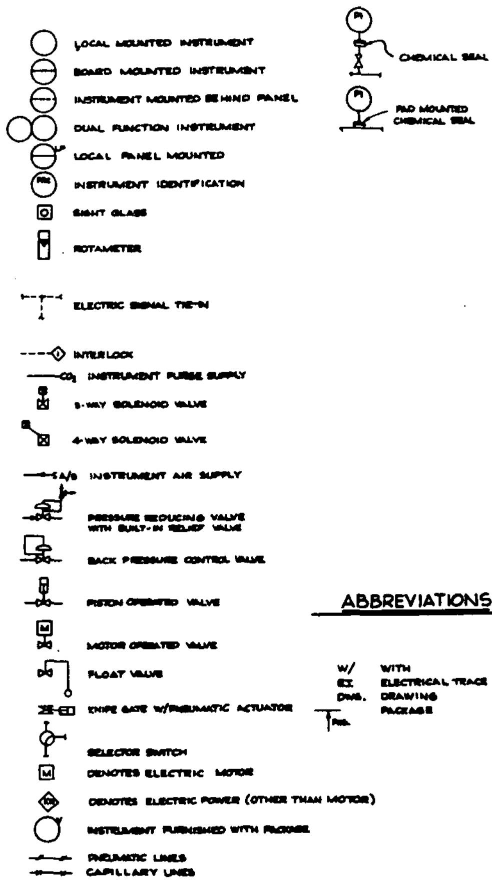
DWG. NO. A-801 SHEET 3 of 3

LIST OF SYMBOLS

PIPING SYMBOLS



INSTRUMENT SYMBOLS



MEANING OF INSTRUMENT IDENTIFICATION LETTERS

	FIRST LETTER (ONE OR TWO LETTERS): MEASURED OR INITIATING VARIABLE	FIRST LETTER: MODIFIER	SUCCEEDING LETTERS (TWO OR THREE LETTERS): READOUT OR PASSIVE FUNCTION	SUCCEEDING LETTERS: OUTPUT FUNCTION	SUCCEEDING LETTERS: MODIFIER
A	ANALYSIS		ALARM		ALARM
B	BURNER FLAME		USER'S CHOICE	USER'S CHOICE	USER'S CHOICE
C	CONDUCTIVITY (ELECT.)			CONTROL	
D	DENSITY (MASS) OR SPEC. GRAV.	DIFFERENTIAL			
E	VOLTAGE (EMF)		PRELIMINARY ELEMENT		
F	FLOW RATE	RATIO FRACTION			
G	GAGING (DIMENSIONAL)		GLASS		
H	HAND (MANUALLY INITIATED)				HIGH
I	CURRENT (ELECTRICAL)		INDICATE		
J	POWER	SCAN			
K	TIME OR TIME SCHEDULE			CONTROL STATION	
L	LEVEL		LIGHT PILOT		LOW
M	MOISTURE OR HUMIDITY				MIDDLE OR INTERMEDIATE
N	USER'S CHOICE		USER'S CHOICE	USER'S CHOICE	USER'S CHOICE
O	USER'S CHOICE		ORIFICE (RESTRICTION)		
P	PRESSURE OR VACUUM		POINT (TEST CONN.)		
Q	QUANTITY OR EVENT	INTEGRATE OR TOTAL			
R	RADIOACTIVITY		RECORD OR PRINT		
S	SPEED OR FREQUENCY	SAFETY		SWITCH	
T	TEMPERATURE			TRANSMIT	
U	MULTIVARIABLE		MULTIFUNCTION	MULTIFUNCTION	MULTIFUNCTION
V	VISCOSITY			VALVE, DAMPER ETC.	
W	WEIGHT OR FORCE		WELL		
X	UNCLASSIFIED		UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED
Y	USER'S CHOICE			RELAY OR COMPUTE	
Z	POSITION			DRIVE OR ACTUATE	

FRC — FLOW RECORDING CONTROLLER ALARM

THIS TABLE IS IN ACCORDANCE WITH I.S.A. STD - S5.1, 1968

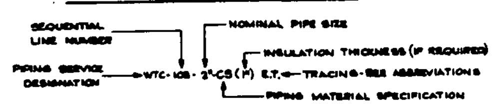
ABBREVIATIONS

W/	WITH
E.T.	ELECTRICAL TRACE
DWG.	DRAWING
PKG.	PACKAGE

LIST OF DRAWINGS

A-200	LEAD SHEET LIMESTONE SLURRY SCRUBBING SYSTEM
A-201	PROCESS FLOW DIAGRAM
A-202	PROCESS FLOW DIAGRAM
A-203	ENGINEERING FLOW DIAGRAM
A-204	ENGINEERING FLOW DIAGRAM

PIPE LINE DESIGNATION



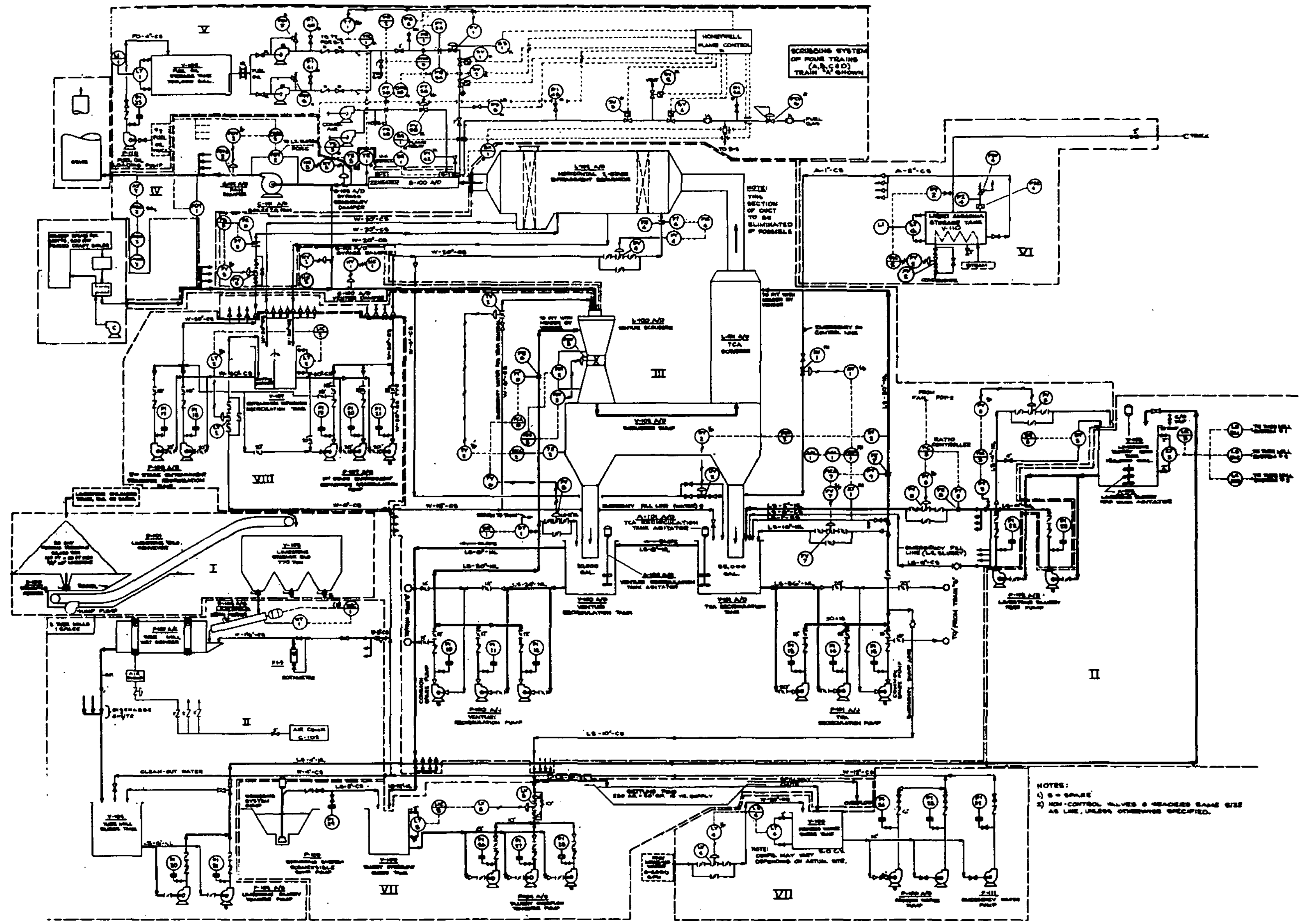
PIPING MATERIAL SPECIFICATIONS

SYMBOL	MATERIAL
CS	CARBON STEEL
NL	NEOPRENE LINED CARBON STEEL
SS	STAINLESS STEEL, 304 OR 316

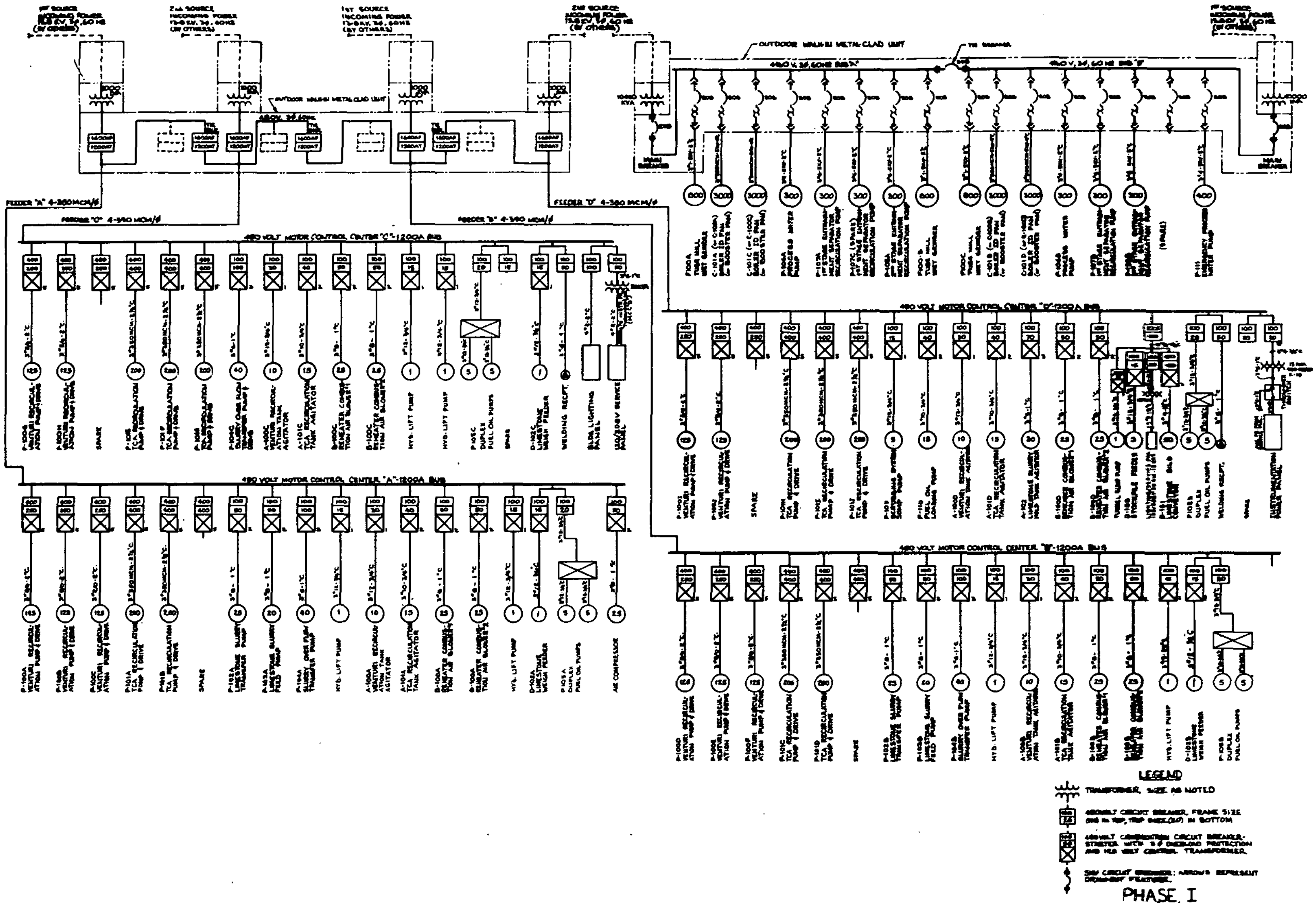
PIPING SERVICE DESIGNATIONS

SYMBOL	SERVICE
A	AMMONIA
FO	FUEL OIL
LS	LIMESTONE SLURRY
W	WATER

Piping information.



Limestone slurry scrubbing system for new 500-megawatt boiler.



Electrical single-line limestone slurry scrubbing system for new 500-megawatt boiler.

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA-R2-73-148a	2.	3. Recipient's Accession No.

4. Title and Subtitle	
A Process Cost Estimate for Limestone Slurry Scrubbing of Flue Gas, Part I	5. Report Date January 1973
	6.
7. Author(s) E.L. Calvin	8. Performing Organization Rept. No.
9. Performing Organization Name and Address Catalytic, Inc. 1515 Mockingbird Lane Charlotte, North Carolina 28209	10. Project/Task/Work Unit No. Task No. 11
	11. Contract/Grant No. 68-02-0241
12. Sponsoring Organization Name and Address EPA, Office of Research and Monitoring NERC/RTP, Control Systems Laboratory Research Triangle Park, North Carolina 27711	13. Type of Report & Period Covered Final
	14.

15. Supplementary Notes

16. Abstracts

Part I of the report describes results of a conceptual design and cost estimate for a wet limestone scrubbing system for removal of sulfur dioxide from the flue gas of a new 500-megawatt steam boiler plant, fired with coal containing a 3.5 percent sulfur. The estimate covers all equipment from the boiler breeching to the stack, and includes: limestone storage and processing, slurry scrubbing with stack gas reheater and accessories, and spent limestone slurry pond disposal and water recovery. The capital cost for the scrubbing system installed with a new boiler plant was estimated to be $20.15 million or an incremental cost of $40.30 per kilowatt of installed power. The operating cost was estimated to be $7.20 million per year, or 2.06 mills per kilowatt hour of electricity generated.

17. Key Words and Document Analysis. 17a. Descriptors

Air Pollution	Limestone
*Desulfurization	Slurries
Flue Gases	Sulfur Dioxide
Washing	Coal
*Cost Estimates	Equipment
Capital Costs	
Operating Costs	
Design	

17b. Identifiers/Open-Ended Terms

Air Pollution Control
Stationary Sources
*Wet Limestone Scrubbing

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited	UNCLASSIFIED	95
	20. Security Class (This Page) UNCLASSIFIED	22. Price

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