USE OF NICKEL STAINLESS STEELS AND NICKEL ALLOYS IN FLUE GAS DESULPHURIZATION SYSTEMS IN THE U.S.A.

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By William L. Mathay, presented at Air Pollution Seminar, Buffalo, NY, U.S.A., Oct 1987.

THE USE OF NICKEL STAINLESS STEELS AND HIGH-NICKEL ALLOYS IN FLUE GAS DESULFURIZATION SYSTEMS IN THE UNITED STATES

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ABSTRACT

The performance of nickel stainless steels and higher nickel alloys in the flue gas desulfurization (FGD) systems of 39 operating power units in the United States is reviewed and discussed. Corrosion problems that have been encountered and the solutions to these problems are presented. The results indicate that the use of alloys in the more aggressive environments of the various FGD systems is finding increased favor.

INTRODUCTION

Case history data on materials usage in flue gas desulfurization (FGD) systems were obtained from 39 different operating power units in the United States. Each of the plants involved was sent a detailed questionnaire starting in late 1985 and extending into 1986 and the replies received were used as the basis for this paper. The complete results of the survey are contained in the book, "Nickel Stainless Steels and High Nickel Alloys for Flue Gas Desulfurization Systems" by Jonathan D. Harrington and the writer which was published under the sponsorship of the Nickel Development Institute, Toronto, Ontario, Canada in February 1987. The intent of the survey was to document the performance of nickel-containing alloys in FGD components as well as to ascertain the types of corrosion problems being encountered and the solutions being applied to those problems. Additionally, it was believed that the data would help design engineers sort out the complexities of materials selection for the equipment used with the different types of sulfur-oxide removal systems.

Today, most FGD processes used in the United States involve wet scrubbing with throw-away products. According to PEI Associates of Cincinnati, Ohio,[1]* such processes using lime/limestone/alkaline fl-yash slurries accounted for nearly 80 percent of the scrubbing systems in use in 1985. They are expected to remain the most widely used but usage is predicted to decrease to about 76 percent by the year 1999. It is not the intent of this paper to review the various scrubbing methods used or to discuss the merits of the methods. However, it should be noted that the present study covered 13 units that used limestone slurries; 10 units that used lime slurries; and 6 units that used lime/alkaline flyash slurries for a total of 29 of 39 units or about 74 percent. Of the other units surveyed four utilize sodium sulfite as the scrubbing medium and recover sulfuric acid; three use dual alkalies (sodium sulfite or sodium carbonate plus lime); two use sodium carbonate; and one is a so-called dry scrubber that uses lime in a spray dryer (see Table 1).

SURVEY RESULTS

The American Society for Testing and Materials (ASTM) Subcommittee D33.09 prepared a special technical publication, STP 837, "Manual of Protective Linings for Flue Gas Desulfurization Systems". This publication utilizes a generic FGD system (Figure 1) and presents a consensus definition of the conditions in the various operating zones (see Tables 2 and 3). The conditions are defined both qualitatively and quantitatively as to chemistry, mechanical factors and temperatures.

For the purposes of this paper, the principal components of the FGD systems are considered to be (1) the inlet flue gas duct at the front end of the system, (2) a separate or contiguous prescrubber or quench section for cooling the gas and removing particulates and some sulfur oxides, (3) the absorber vessel or section where an alkaline slurry or solution is sprayed into the gas to remove most of the remainder of the sulfur oxides, (4) the outlet duct which provides the entry area for the gas from the by-pass duct and the possible location for a reheater, and (5) the stack or chimney for exhausting the flue gas to the atmosphere. Additionally, the systems have spray nozzles, dampers, pumps, valves and tanks, but these usually are not as much a concern as the components just mentioned.

Prescrubber Vessels

A number of the power plant FGD systems use prescrubbers. These present a variety of environments with pH values that are strongly acidic to moderate being encountered depending on whether plain water or scrubbing liquor is used for quenching. Too, temperatures may approach 300F (149C) and erosion can occur, particularly if there is liquid impingement, turbulence or restriction of gas/liquid flow.

A review of the practices at the units surveyed indicates that of those with separate prescrubbers, a large majority utilize alloy construction. For example, Arizona Public Service Cholla Unit 1 originally used Type 316L stainless steel for the flooded disc and throat (Figure 2) in the prescrubber but after repeated problems with

*See references.

erosion-corrosion and pitting attack, an Alloy G disc and throat were installed in 1974. Since then there have been no problems with the Alloy G. The Type 316L stainless-steel prescrubber walls also exhibited erosion-corrosion and in 1974 they were covered with an epoxy membrane and acid-resisting bricks. Maintenance on the brick lining-/membrane is required every 6 months to a year.

Cholla Unit 2, which was constructed in 1978 and is similar in design to Cholla 1, uses a prescrubber with a carbon-steel shell and an organic lining. In the tapered section around the flooded disc the shell is not only covered with an organic membrane but also silicon carbide brick. In this unit, the disc is constructed of Alloy C-276 and although there have been no problems with the disc, the lining materials require repair on an annual basis.

Kansas City Power and Light La Cygne Unit 1 has a venturi prescrubber (Figure 3) which is constructed of Type 316L stainless steel with a concrete lining. The lining has required periodic patching since start-up in 1973.

Louisville Gas & Electric Cane Run Unit 4 has a prescrubber/quencher which is constructed of carbon steel with a concrete lining and a Type 316L stainless-steel floor (Figure 4). This unit started up in 1976 and by 1980 failure of the concrete lining had progressed to the point that it was replaced with a Type 316L stainless-steel lining. Since then performance has been satisfactory.

Minnesota Power & Light Company Clay Boswell Unit 4 (Figure 5) uses variable throat venturis which are constructed of rubber-lined carbon steel. Punctures and wear problems have been encountered since start-up in 1980 but the design utilizes sections that are readily accessible and replaceable.

Public Service of New Mexico San Juan Units 1, 2, 3 and 4 (Figure 6) all have venturi prescrubbers that are constructed of carbon steel with a lining of acid-resisting bricks backed up with an organic membrane. However, the inlet duct to the venturi is of Type 316L stainless steel. Although not specifically reported, it is believed that periodic maintenance of the lining has been required over the 5 to 9 years the units have been in operation.

Tennessee Valley Authority Widows Creek Units 7 and 8 (Figure 7) both have venturi prescrubbers. The Unit 7 prescrubbers are constructed of Type 317L stainless steel with refractory tile linings. There are rods in the venturi which were originally of refractory material but which have been replaced with Type 316L stainless-steel rods after start-up in 1981.

Widows Creek Unit 8 has variable-throat venturi prescrubbers constructed of high-molybdenum Type 316L stainless steel. The floor and hoppers were of high-strength low-alloy steel lined with neoprene, but the neoprene failed and was replaced with high-molybdenum Type 316L stainless steel. The venturi blades are covered with ceramic tiles. Performance has apparently been satisfactory since late 1979 when the replacements were made.

Quencher/Absorber Vessels

A number of the power plant units surveyed have prescrubber or quench sections that are located in the top or bottom of the absorber vessel. The environments in the quench section can be as severe as in those in separate prescrubber/quenchers. The absorber section usually has mild to moderate environments, although there can be problems from an abrasion standpoint where there is impingement from sprays. Arizona Public Service Cholla Unit 4 (Figure 8) has its quencher in the bottom. Both the scrubber and the absorber sections are constructed of organic-coated carbon steel, but after 4 years operation, the coating has failed and alternative coatings are being evaluated. Interestingly, the inlet duct to the quench section is constructed with an Alloy G floor and Jessop JS700 walls. These alloys are performing well.

Arizona Public Service Four Corners Units 1, 2 and 3 (Figure 9) have venturi quench sections at the top. The inlet duct is of carbon steel lined with acid-resisting bricks and mortar. The sides and floor of the quench and absorber sections are constructed of carbon steel coated with flake-glass-filled polyester. Because of continuing failures, the coating must be oversprayed annually or more often as needed with a mica-filled polyester. The plumb bob is carbon steel with a Type 316L stainless-steel weld overlay but the shaft is solid Type 316L stainless steel.

The Four Corners Units 4 and 5 do not have prescrubbers or quench sections as contrasted with the first three units (Figure 10). The absorber inlet is constructed of carbon steel clad with Alloy C-276 and the absorber itself has Type 317LM stainless-steel walls and floor. Performance reportedly has been satisfactory since start-up in 1984.

Basin Electric's Laramie River Units 1 and 2 (Figure 11) utilize packed towers that have a quench section in the bottom and an absorber section in the top. The bottom section was constructed of Alloy 904L and high-molybdenum Type 316L stainless steel was used in the upper section. Shortly after start-up of Unit 1, pitting was observed in the quench sections of the towers. The pitting was observed primarily in the weld metal but also in the parent metal and crevice attack was encountered at weld metal/parent metal contacts and at weld spatter areas. The problems and their solution have been described in the literature[2] but suffice it to say that overmatching weld electrodes were required for weld repair and continuous electrochemical protection was provided for the Alloy 904L. The high-molybdenum Type 316L stainless-steel absorber sections are performing well as are inlet ducts which have Alloy 904L sides and tops and Alloy G floors.

The Laramie River Unit 3 uses a so-called dry scrubber (Figure 12) which is constructed of carbon steel. Reportedly, operational problems have plagued the unit since start-up.

Kansas City Power & Light LaCygne Unit 1 has a Type 316L stainless-steel absorber but the sump which is common to both the absorber and the prescrubber is Type 316L stainless steel with a concrete lining. This lining must be patched periodically.

Louisville Gas & Electric Cane Run Unit 4 has a Type 316L stainless-steel absorber which has been performing satisfactorily since start up in 1976. Cane Run Unit 5 (Figure 13) originally had carbon-steel absorbers that were coated with glass-flake-reinforced polyester. The coating failed and was patched repeatedly until a Type 316L stainless-steel lining was applied. The stainless-steel lining has performed well except for a few leaks at welds.

Cane Run Unit 6 (Figure 14) has carbon-steel absorbers that are coated with a flake-glass-filled polyester. The coating requires frequent patching.

Louisville Gas & Electric Mill Creek Units 1 and 2 have absorbers that are constructed of Type 316L stainless steel and these have performed satisfactorily since late 1981 when the units went into operation. On the other hand, Units 3 and 4 (Figure 15) were redesigned and rebuilt in 1985 and 1986 respectively because of continuing problems with the cementitious linings on the carbon steel in the prescrubbers and absorbers. In the new design, the prescrubbers were eliminated and the inlet to the absorbers was lined with Alloy C-276. The absorbers themselves were lined with Type 317LM stainless steel and as of this date these materials have proven satisfactory.

At Minnesota Power and Light Clay Boswell Unit 4 the absorbers are rubber-lined carbon steel with Type 316L stainless-steel sieve trays. Reportedly the absorbers have been satisfactory since operations began in 1980.

Montana Power Company's Colstrip Units 1 and 2 (Figure 16) have venturi quench sections at the top of the absorbers. The inlets are Type 316L stainless steel and the venturis are of carbon steel with acid-resistant brick liners and a Type 316L stainless-steel plumb bob. Absorber walls were of carbon steel with an 80-mil-thick organic coating but the coating required repair at least every 3 years. There also was excessive wear on the walls at areas contacted by sprays so neoprene-covered Type 316L stainless-steel wear plates were installed. Trays are also Type 316L stainless steel and the stainless steels are reported to be doing well.

Colstrip Units 3 and 4 (Figure 17) were put on line in 1983 and 1985, respectively. They, too, have venturi quench sections at the tops of the absorber vessels. These vessels have Type 317LM stainless-steel inlets and walls and the floors are of carbon steel clad with Type

317LM stainless steel. The plumb bobs in the venturis are of Type 317L stainless steel. No particular problems have been reported to date.

New York State Electric and Gas Company Somerset Unit 1 (Figure 18) which started up in July of 1984 has Alloy 625 absorber inlets. The walls and floor of the absorber vessels are of carbon steel coated with a flake-glass-filled polyester. Frequent lining repair has been required since the start-up three years ago. Absorber trays are of Alloy G-3 and are performing well.

Northern Indiana Public Service Schahfer Units 17 and 18 (Figure 19) are also relatively new having started up in 1983 and 1985, respectively. Inlet ducts and inlets, walls and floors of the absorbers are constructed of Type 317LM stainless steel. Contact discs in the absorbers are also of Type 317LM stainless steel. To date no problems have been reported in these areas.

Pacific Power and Light Jim Bridger Units 2 and 4 (Figure 20) have similar FGD systems even though they are from different suppliers. At Unit 2, which started up in 1986, absorber inlets are of carbon steel coated with concrete over a membrane of reinforced vinyl ester. The walls and floors of the absorber are constructed of high-molybdenum Types 316L and 317L stainless steels, respectively. At Unit 4, which started up in 1979, there is quench zone at the inlet of the absorber vessels which is constructed of Type 317LM stainless steel. The absorber vessels themselves are of neoprene-lined carbon steel and the sieve trays are of Type 317LM stainless steel. There have been no reports of problems with either of the units.

Public Service of New Mexico San Juan Units 1, 2, 3 and 4 have FGD units with Alloy 625 inlets. The absorbers are of double-wall concrete with a layer of acid-resisting bricks over an organic membrane in the lower section of the vessel. The upper section is tile-lined. Upper trays are high-molybdenum Type 316L stainless steel and the bottom tray is of Alloy C-276. Reportedly, the systems have performed well with only periodic maintenance problems.

Springfield Water Light and Power Company Dallman Unit 3 (Figure 21) has an FGD system that uses packed towers which have a quench section in the bottom and an absorber section in the top. Alloy 904L is used in the quench section and high-molybdenum Type 316L stainless steel is used in the absorber section. The inlet duct is constructed of carbon steel except for the last few feet which are of Alloy 904L. Corrosion problems were encountered at the carbon steel/Alloy 904L junction. Sheets of Alloy 625 were welded over the junction and no further problems were encountered. No other problems have been encountered since start-up in 1985.

Tampa Electric Big Bend 4 (Figure 22) also has an absorber vessel made up of two sections. The lower or quench section is constructed of Alloy 625 and the upper absorber section is of Alloy 904L. The inlet is also of Alloy 625. These materials have performed well since start-up in 1985.

Tennessee Valley Authority (TVA) Paradise Units 1 and 2 (Figure 23) have combined venturi quenchers and absorbers in their FGD systems. The inlets to these are of high-strength low-alloy steels and the venturis are of Type 317L stainless steel with an acid-brick lining. The plumb bob is of epoxy-coated steel. The absorbers, too, were constructed of Type 317L stainless steel. Performance of the alloys has been satisfactory since start-up in 1983.

TVA Widows Creek Units 7 and 8 have FGD systems with absorbers that are constructed of different materials. Unit 7 has Type 317L stainless-steel absorbers and Unit 8 has rubber-lined high-strength low-alloy steel absorbers. The former have performed well but the latter have experienced failures of the linings. The linings are being replaced with high-molybdenum Type 316L stainless steel as failures occur.

Outlet Ducts/Reheaters

The environments in the outlet ducts although considered mild from an erosion standpoint can be moderate to severe from a temperature standpoint and severe from a chemistry (pH value) standpoint.

Arizona Public Service Cholla Unit 1 has tried numerous organic coatings in the outlet duct but all failed and an Alloy C-22 lining is presently being evaluated. A Type 316L stainless-steel shell and tube reheater is being used, but since it has only a 6-year service life plans are to replace it with an Alloy C-22 or C-276 unit.

Cholla Unit 2 has outlet ducts that are of carbon steel coated with a polyester resin up to the fan and with a glass-flake-filled vinyl ester from there to the stack. An Alloy 625 shell and tube reheater is being used but because of periodic tube failures, higher alloy tube materials are being considered. There have been no major problems with the organic coatings but periodic repairs are necessary.

Cholla Unit 4 has a carbon-steel outlet duct that is lined with an organic coating but there have been no reports of problems with the duct.

Arizona Public Service Four Corners Units 1, 2 and 3 have outlet ducts that are of carbon steel supposedly lined with Type 316L stainless steel. However, the occurrence of corrosion problems in the heat-affected zones indicates that the low carbon grade of stainless steel was not used.

Four Corners Units 4 and 5 have outlet ducts of carbon steel lined with concrete over a membrane of mica-filled polyester. Since the Units started up in late 1984, performance has been unsatisfactory.

Basin Electric Laramie River Units 1 and 2 have outlet ducts that are constructed of Type 317LM stainless steel up to the damper. Beyond the damper, the duct is constructed of Alloy 904L. Performance has been satisfactory since start-up.

Kansas City Power & Light LaCygne Unit 1 has outlet ducts that are of carbon steel coated with a glass-flake-filled vinyl ester. The duct must be recoated every six months.

Louisville Gas & Electric Cane Run Units 4, 5 and 6 have carbon-steel outlet ducts that are now lined with stainless steel. Unit 4 originally had an organic coating on it but after frequent failures it was replaced with concrete. This, too, failed frequently and ultimately was replaced with a Type 316L stainless-steel lining. At Unit 5, the organic coating ahead of the reheaters failed and was replaced with Type 316L stainless steel. A Type 317LM stainless-steel lining was installed from the reheater to the chimney in the outlet ducts of both Units 5 and 6. Reportedly, the stainless steels are performing well.

The reheaters at Unit 5 are carbon-steel shell and tube units with Type 316L stainless-steel baffles. However, because of frequent tube failures, plans are to eliminate the reheaters entirely. Unit 6 originally had external oil-fired reheaters but these now have been eliminated.

Louisville Gas & Electric Mill Creek Units 1, 2, 3 and 4 all have carbon-steel outlet ducts. General corrosion of the outlet ducts at Units 1 and 2 have occurred but it is believed that the reheat from the carbon-steel reheater at the top of the absorber has kept the attack to a minimum. However, at Units 3 and 4, the organic lining in the outlet duct failed ahead of the reheater and corrosion occurred near the absorber necessitating relining. Type 317LM stainless steel was used and is performing well.

The original reheaters at Unit 4 had carbon-steel tubes with Type 316L stainless-steel fins but as might be expected galvanic corrosion occurred and replacement was necessary. The new reheaters have top rows of Type 317LM stainless-steel tubes with fins of the same composition and bottom rows of Alloy 625 tubes with no fins. No further corrosion problems have been reported.

Minnesota Power & Light Clay Boswell Unit 4 has a carbon-steel outlet duct lined with flake-glass-filled polyester except for a short section of Type 317LM stainless steel where the diffusers from the external reheaters are located.

Montana Power & Light Colstrip Units 1, 2, 3 and 4 have outlet ducts that are of organic-coated carbon steel. The ducts at the reheaters at Units 1 and 2 are of Type 316L stainless steel, but the coating elsewhere in the ducts requires patching and repair on a regular basis.

The reheaters at all four Colstrip Units are plate-type heat exchangers with Alloy G in the lower sections and Alloy 625 in the upper sections. Problems with cracking of welds have been reported at Units 1 and 2, but otherwise performance has been acceptable.

New York State Electric & Gas Somerset Unit 1 has outlet ducts that are of polyester-lined carbon steel but at the by-pass/reheat area the duct is lined with heat-resistant bricks.

Northern Indiana Public Service Schahfer Units 17 and 18 have outlet ducts that are of Type 317LM stainless steel from the absorber to the isolation damper past the reheater. After the damper, the duct is high-molybdenum Type 316L stainless steel. The Type 317LM stainless steel after the reheater and the Type 316L stainless steel beyond are showing perforations. Plans are to line these areas with either Alloy C-22 or Alloy C-276.

The reheaters at the Schahfer Units have Alloy 625 tubes with Type 317LM stainless-steel tube supports. Some leakage has been reported in the bottom row of tubes but otherwise no problems have been encountered.

Pacific Power & Light Jim Bridger Units 2 and 4 both have carbon-steel outlet ducts coated with a reinforced vinyl ester. However, at Unit 2 the section of the duct ahead of the isolation damper is of Type 317L stainless steel. Unit 2 is the newest of the units, having gone into service in June 1986.

Public Service of New Mexico San Juan Units 1, 2, 3 and 4 all have high molybdenum Type 316L stainless-steel outlet ducts from the absorbers to the reheaters. From the reheaters to the chimney/stack, the outlet duct is carbon steel lined with a flake-glass-filled vinyl ester. The stainless-steel sections have performed well but periodic repairs and patching are required in the organic-coated areas.

Springfield Water, Light & Power Dallman Unit 3 had outlet ducts of Alloy 904L but severe pitting was encountered at the by-pass gas entry point. A concrete lining was installed up to the breeching area and beyond that a fluoroelastomer lining was applied. The concrete lining failed and is being replaced with a lining of Alloy C-276.

Tampa Electric Big Bend Unit 4 has a carbon-steel outlet duct which is covered with a 150- to 175-mil-thick polyester coating. The section of duct supplying reheat from an external carbon-steel shell and tube exchanger was originally Alloy 904L but it corroded badly within one year after start-up. A lining of Alloy C-276 has been applied over the corroded areas and performance is satisfactory.

Tennessee Valley Authority Paradise Units 1 and 2 and Widows Creek Unit 7 all have unlined high-strength low-alloy steel outlet ducts. At the Paradise Units, the section of the outlet duct where reheat mixing occurs is constructed of Type 317L stainless steel. Here, the shell and tube reheaters have Type 317L and 316L stainless-steel tubes in the first and second stages, respectively. At Widows Creek 7 the reheaters have carbon-steel tubes but because of corrosion problems these will be replaced with Type 316L stainless steel tubes.

TVA Widows Creek Unit 8 has a high-molybdenum Type 316L stainless-steel outlet duct. Here, also, corrosion of the carbon-steel tubes in the reheaters has led to replacement with Types 316L and 317L stainless-steel tubes.

Chimneys/Stacks

The chimneys/stacks carry the cleaned flue gases to the atmosphere. The gases are usually highly acidic and at temperatures below the acid-gas dew point. Of the utilities surveyed 26 out of the 39 units utilize reinforced concrete chimneys with an acid-resisting brick and mortar liner. One, Basin Electric Laramie River Unit 3, has a fiberglass-reinforced plastic stack. Spray nozzles are installed to protect against high temperatures. Arizona Public Service Cholla Unit 2 has a reinforced concrete chimney with an organic-coated steel liner and it, too, has spray nozzles installed to guard against temperature excursions.

Kansas City Power & Light LaCygne 1 and Montana Power Colstrip Units 1, 2, 3 and 4 also have reinforced concrete chimneys with organic-coated steel liners. Pacific Power & Light Jim Bridger Unit 2 has a reinforced concrete chimney that has a high-strength low-alloy steel/chromium stainless steel liner that is coated with a fluoroelastomer. Apparently none of these has a protective spray system.

Louisville Gas & Electric Mill Creek Units 1 and 2 have reinforced concrete chimneys with uncoated steel liners. Surprisingly, there have been no reported corrosion problems.

Louisville Gas & Electric Cane Run Units 4 and 5 have reinforced concrete chimneys with monolithic cement liners and these linings have been failing periodically. The lining at Cane Run Unit 5 will be replaced with clad Alloy C-276. Interestingly, Cane Run 6 has a steel liner which has been "wallpapered" (lined) with Alloy C-276.

Conclusions

On the basis of the survey that was made of the FGD systems at 39 different operating power units, it was found that increasing use is being made of the stainless steels and higher nickel-containing alloys. Also, there were successful applications of organic coatings identified but in those instances where replacements were required, alloy linings often were installed.

REFERENCES

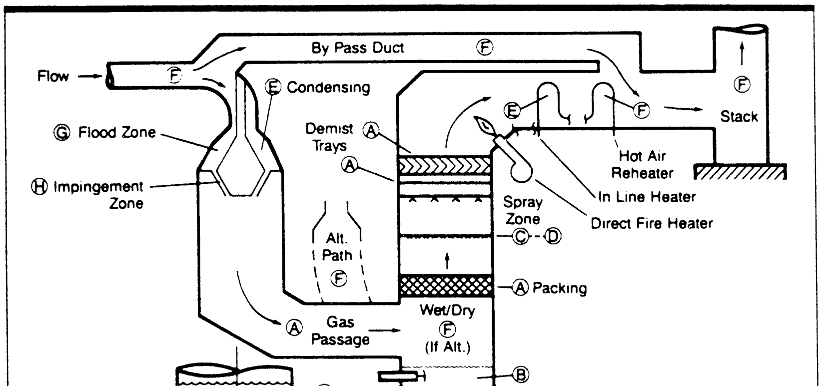
1. Project Summary, Utility FGD Survey January - December 1985 by PEI Associates, Inc., Cincinnati, Ohio. DOE Contract No. DE-ACO5-840R21400, November 1986.
2. "Corrosion Performance in FGD Systems at Laramie River and Dallman Stations" by G. T. Paul and Ralph W. Ross, Jr. Proceedings of CORROSION/83 Symposium on Performance of Constructional Material in Flue Gas Desulfurization Systems. CORROSION/84 Symposium on Materials Evaluation and Environmental Effects on Corrosion in Flue Gas Desulfurization Systems. Edited by G. H. Koch and N. G. Thompson, 1984.

ADDENDUM

Since the presentation of this paper some of the power stations discussed have made additional changes in the materials utilized.

Figure 1

OPERATING ZONE GENERIC FGD SYSTEM ASTM D-33.09



Note: Callout letters refer to codes found in Table 2.

Figure 2

CHOLLA UNIT 1

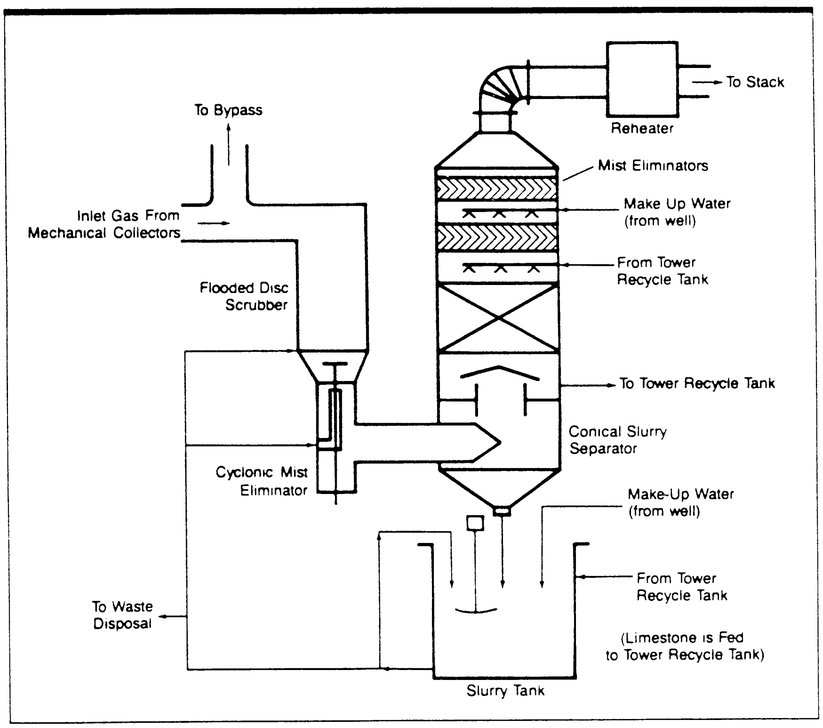


Figure 3

LA CYGNE UNIT 1

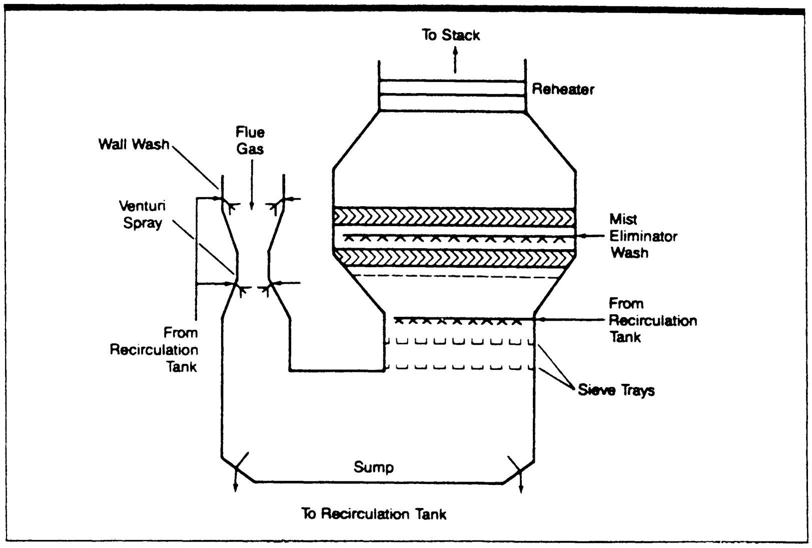


Figure 4

CANE RUN UNIT 4

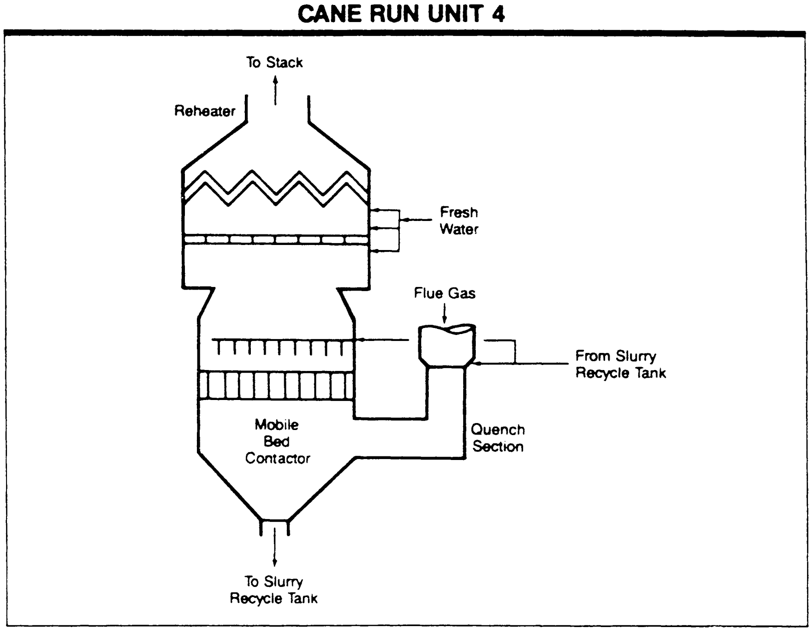


Figure 5

CLAY BOSWELL UNIT 4

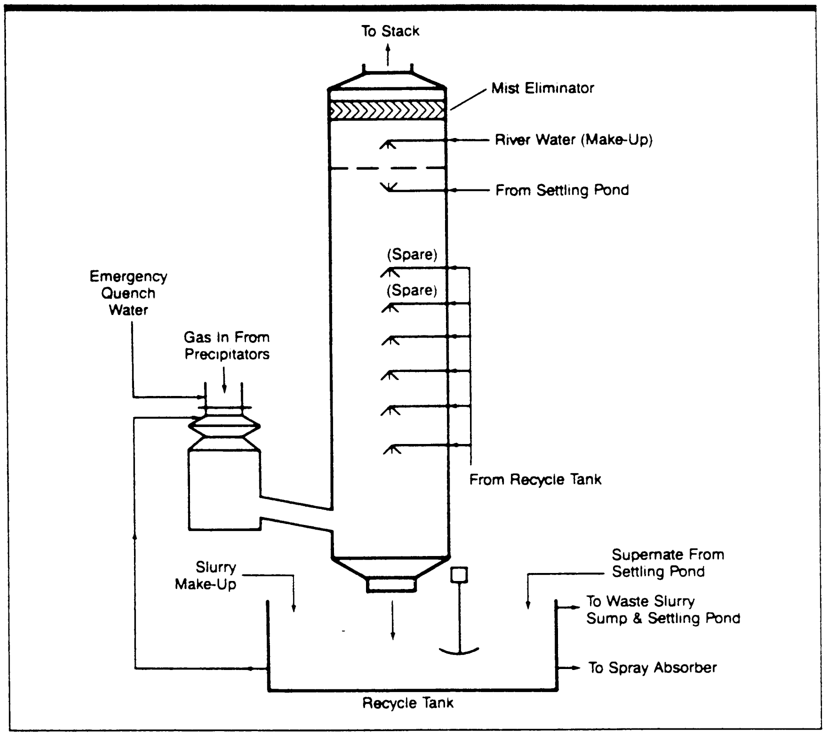


Figure 6

SAN JUAN UNITS 1, 2, 3, AND 4

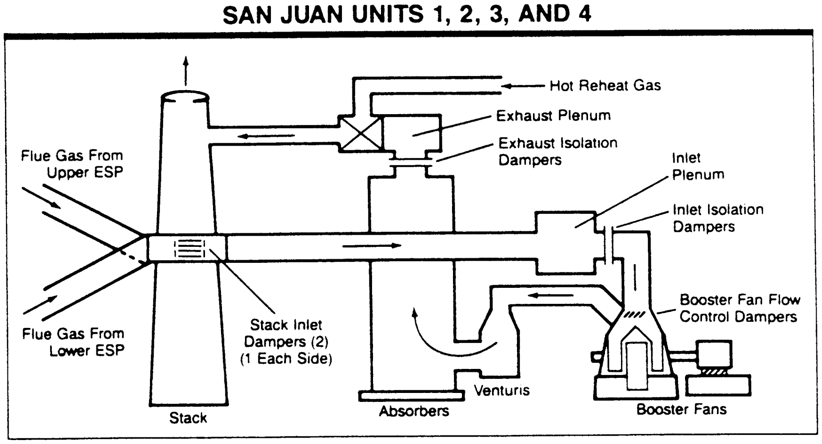


Figure 7

WIDOWS CREEK UNIT 7

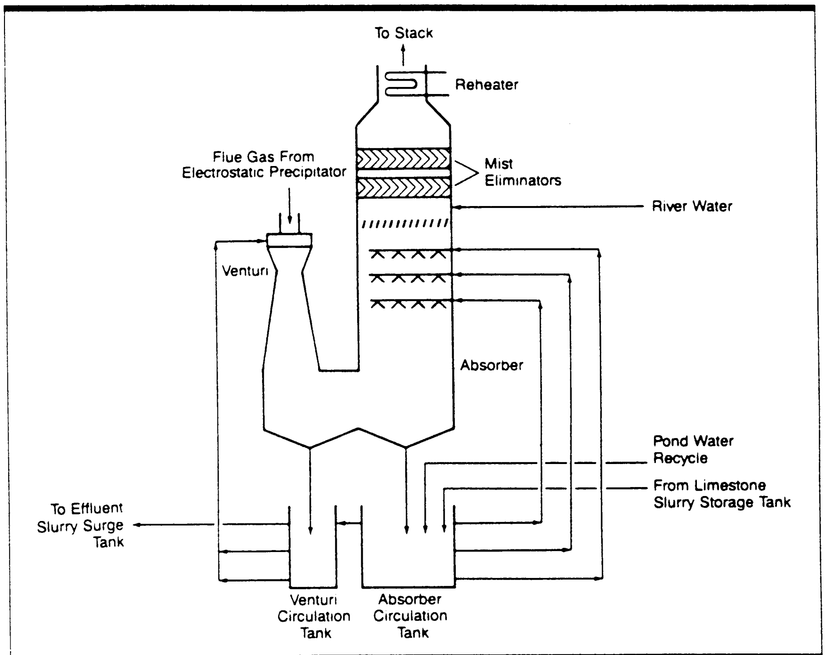


Figure 8

CHOLLA UNIT 4

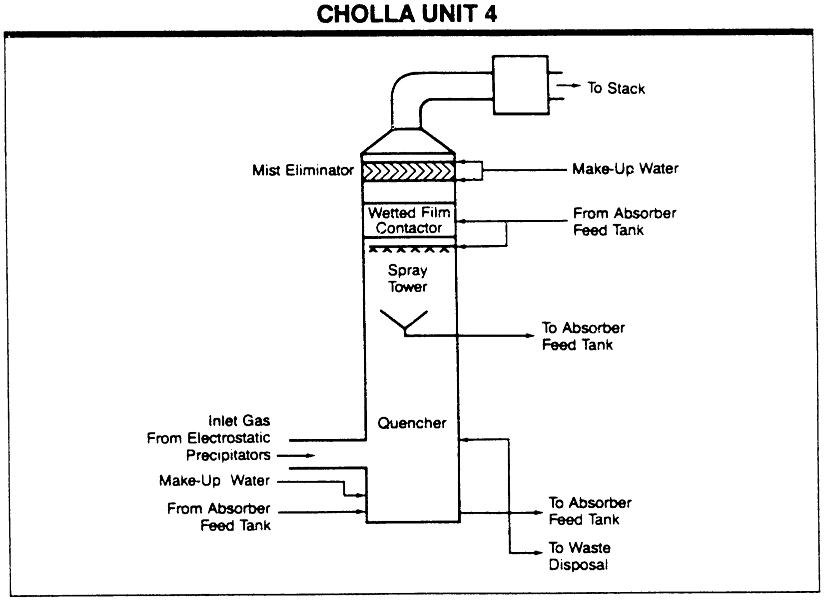


Figure 9

FOUR CORNERS UNITS 1, 2, AND 3

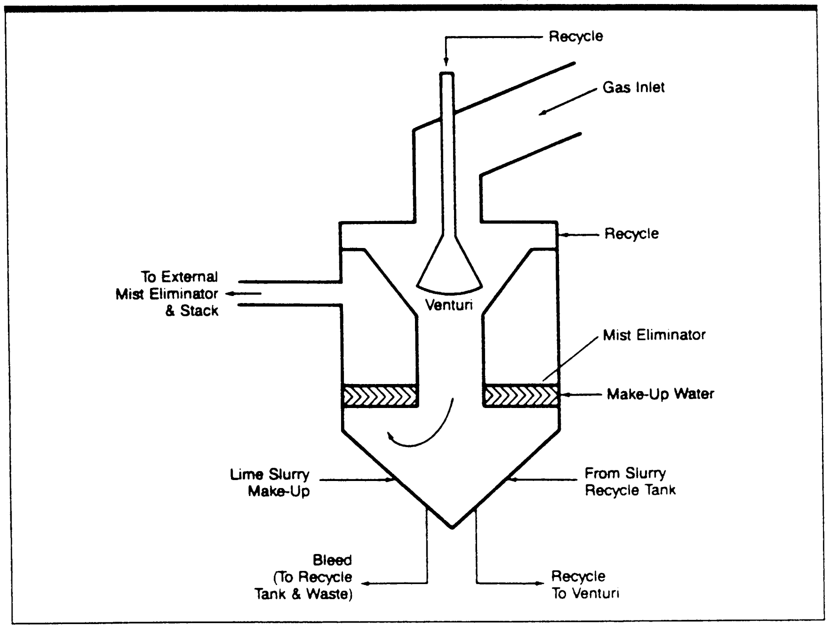


Figure 10

FOUR CORNERS UNITS 4 AND 5

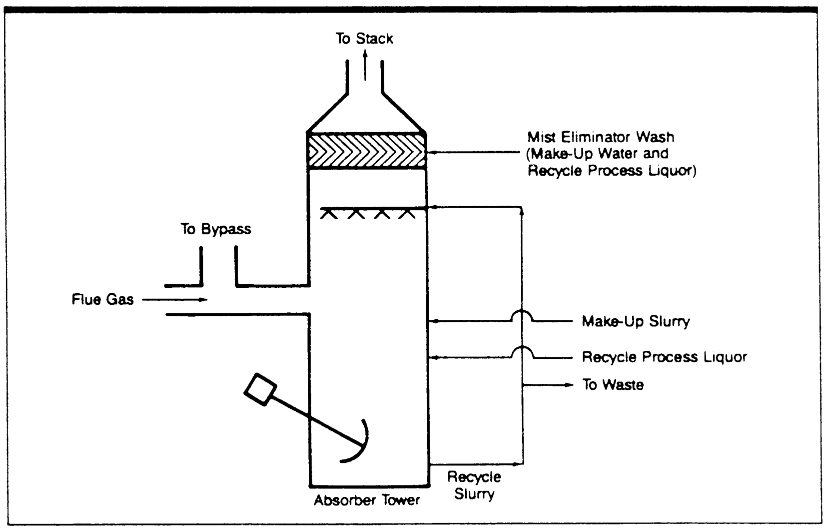


Figure 11

LARAMIE RIVER UNITS 1 AND 2

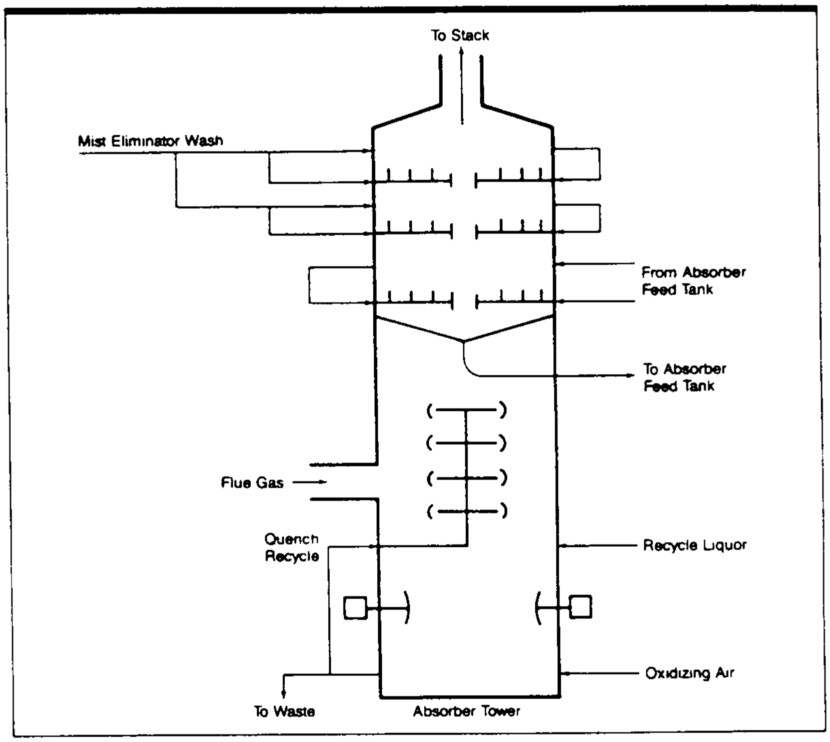


Figure 12

LARAMIE RIVER UNIT 3

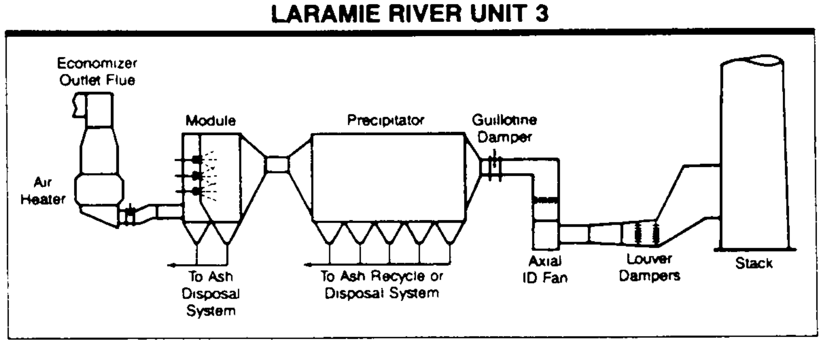


Figure 13
CANE RUN UNIT 5

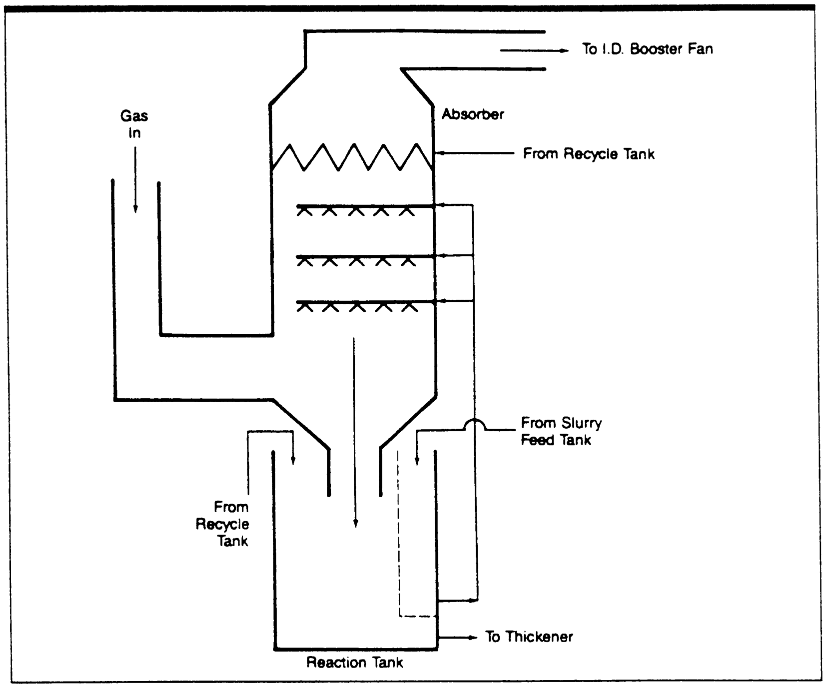


Figure 14
CANE RUN UNIT 6

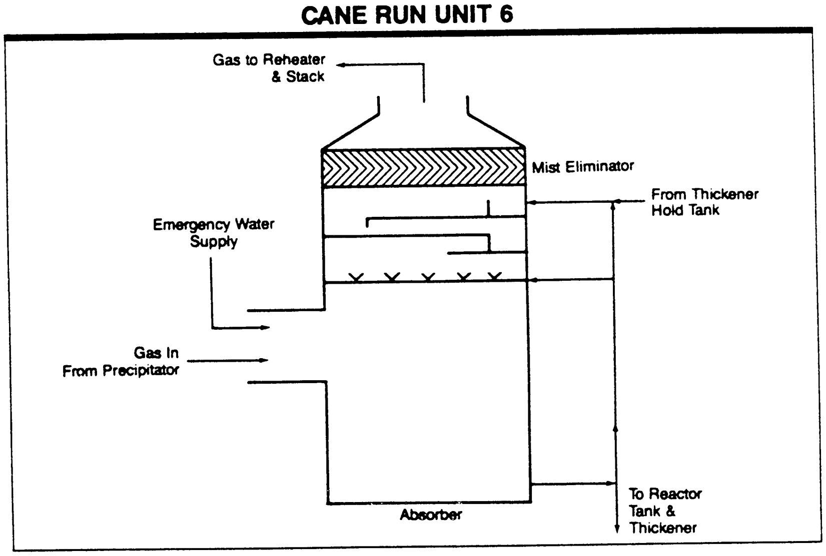


Figure 15

MILL CREEK UNITS 3 AND 4

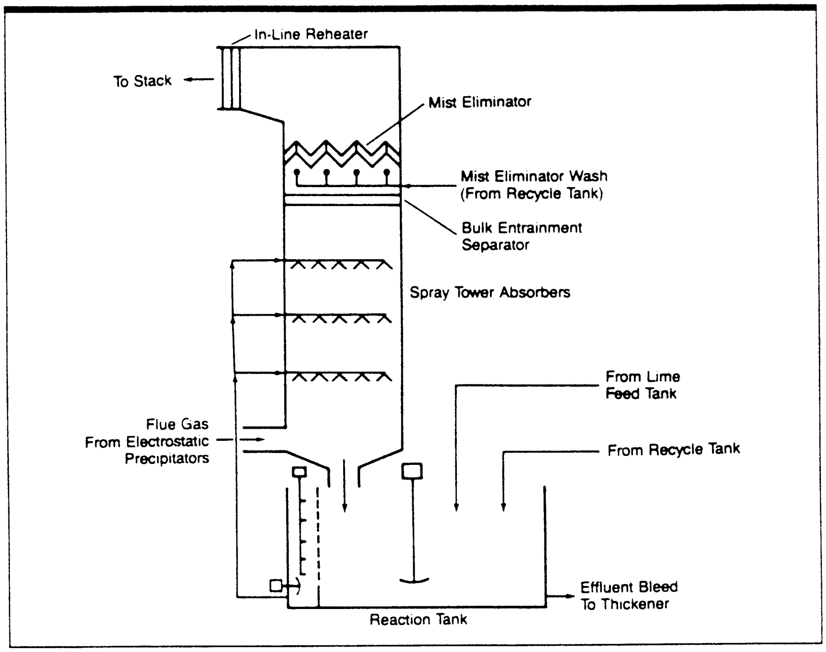


Figure 16

COLSTRIP UNITS 1 AND 2

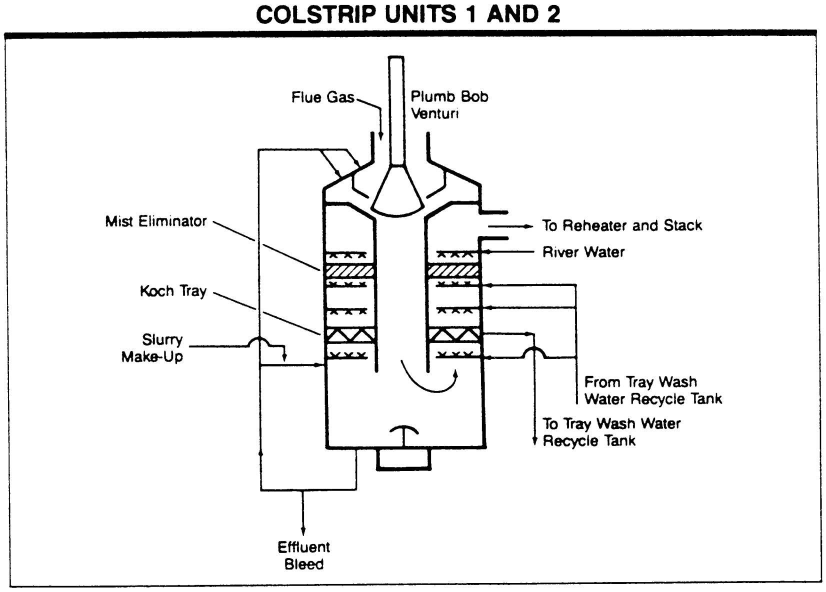


Figure 17

COLSTRIP UNITS 3 AND 4

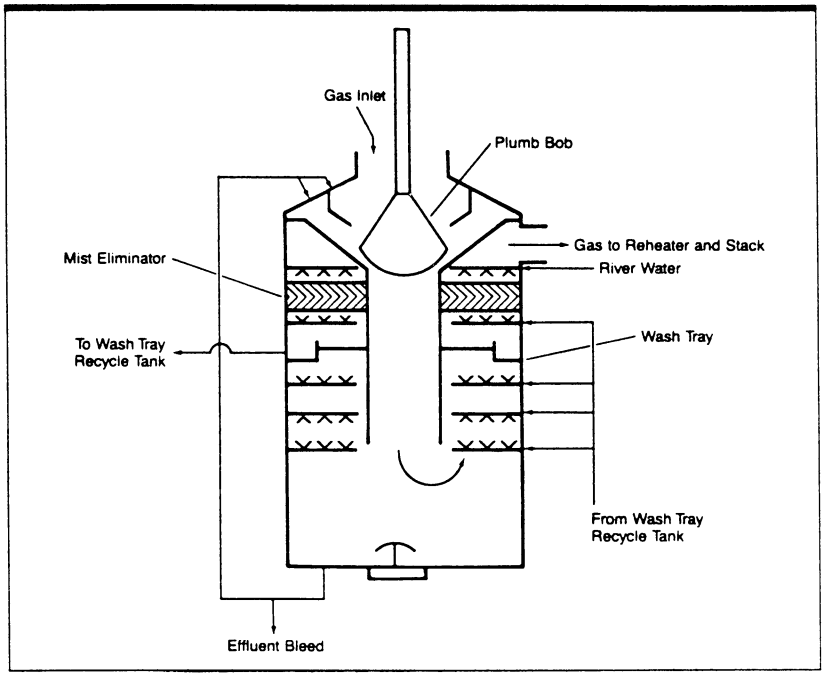


Figure 18

SOMERSET UNIT 1

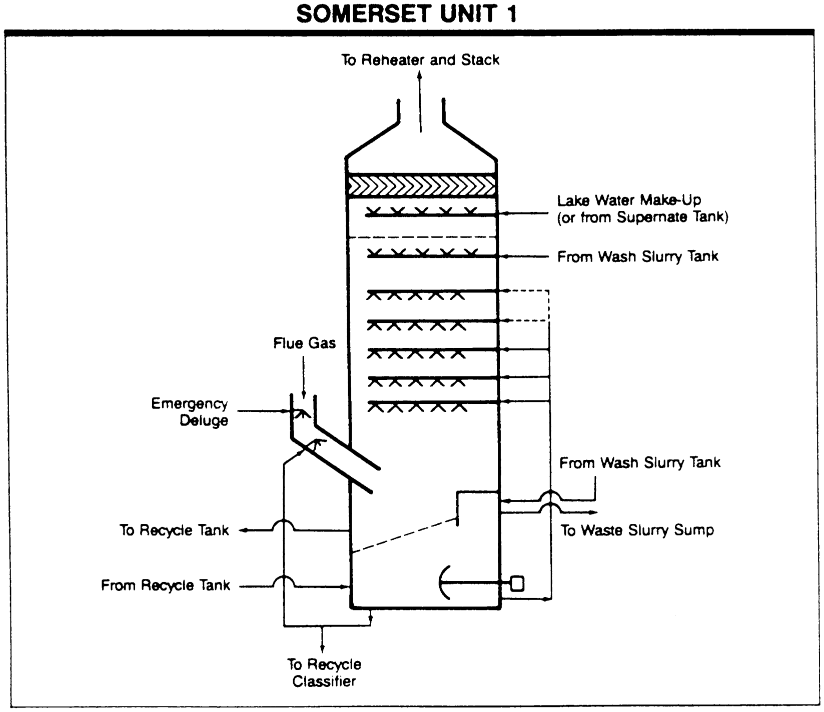


Figure 19

SCHAHFER UNITS 17 AND 18

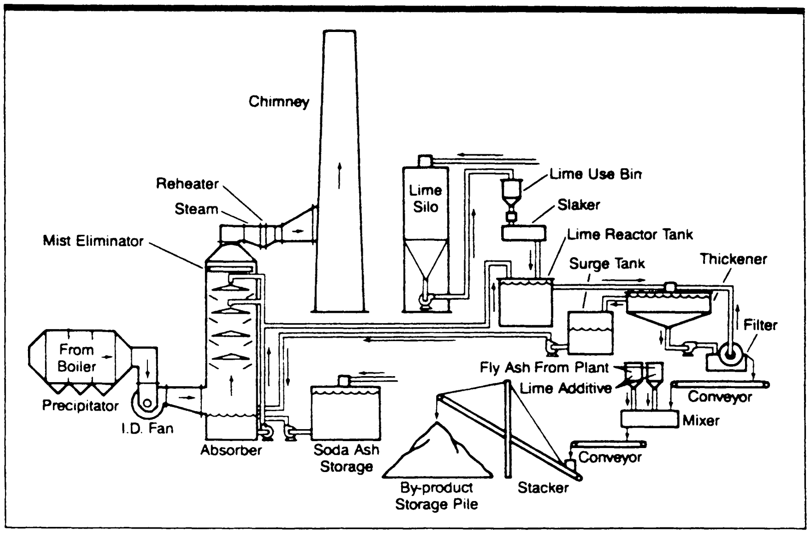


Figure 20

JIM BRIDGER UNIT 2

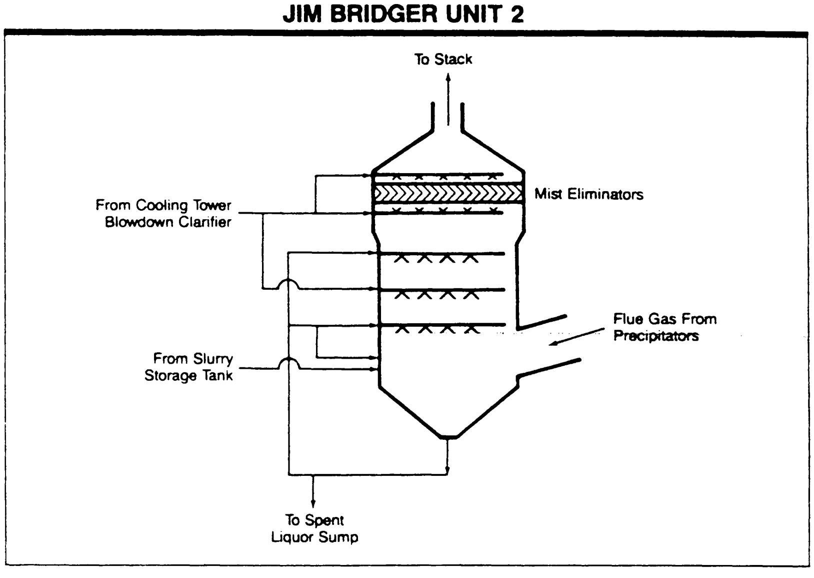


Figure 21

DALLMAN UNIT 3

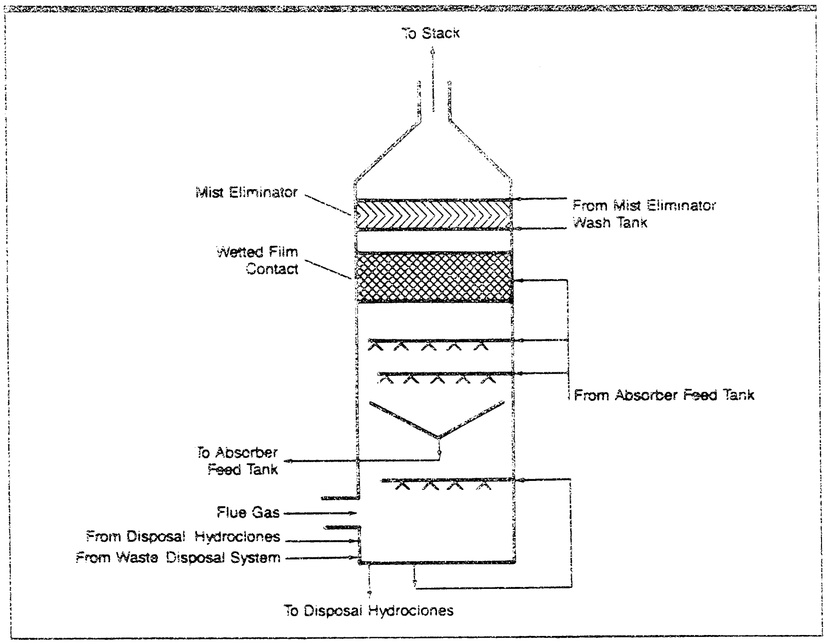


Figure 22

BIG BEND UNIT 4

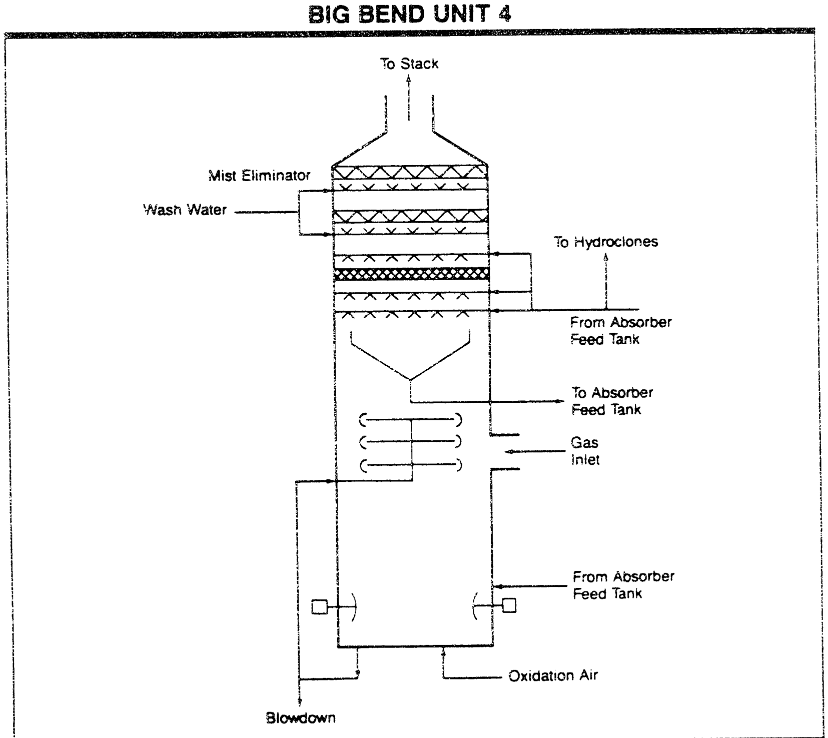


Figure 23

PARADISE UNITS 1 AND 2

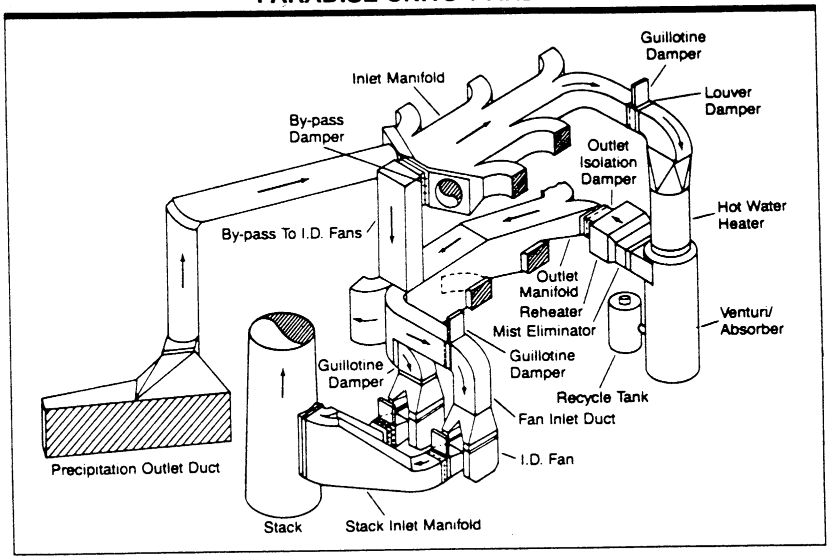


Table 1
UTILITIES INVOLVED IN FGD SURVEY

Utility	Unit	Location	Scrubbing medium	Start-up date
Arizona Public Service	Cholla 1, 2, 4	Joseph City, AZ	Limestone	1973, 1978, 1981
Arizona Public Service	Four Corners 1, 2, 3	Fruitland, NM	Lime/alk. flyash	1979, 1979, 1980
Arizona Public Service	Four Corners 4, 5	Farmington, NM	Lime	1984, 1984
Basin Electric Cooperative	Laramie River 1, 2	Wheatland, WY	Limestone	1980, 1981
Basin Electric Cooperative	Laramie River 3	Wheatland, WY	Lime — dry	1982
Kansas City Power & Light	LaCygne 1	LaCygne, KS	Limestone	1973
Louisville Gas & Electric	Cane Run 4, 5	Louisville, KY	Carbide Lime	1976-1977
Louisville Gas & Electric	Cane Run 6	Louisville, KY	Sodium carbonate & lime	1979
Louisville Gas & Electric	Mill Creek 1, 2, 3, 4	Louisville, KY	Carbide lime	1980, 1981, 1985*, 1986*
Minnesota Power & Light	Clay Boswell 4	Cohasset, MN	Lime/alk. flyash	1980
Montana Power	Colstrip 1, 2	Colstrip, MT	Lime/alk. flyash	1975, 1976
Montana Power	Colstrip 3, 4	Colstrip, MT	Lime	1983, 1985
N.Y. State Electric & Gas	Somerset 1	Somerset, NY	Limestone	1984
Northern Indiana Public Service	Schahfer 17, 18	Wheatfield, IN	Sodium sulfite & lime	1983, 1985
Pacific Power & Light	Jim Bridger 2, 4	Rock Springs, WY	Sodium carbonate	1986, 1979
Public Service of New Mexico	San Juan 1, 2, 3, 4	Waterflow, NM	Sodium sulfite**	1978, 1978, 1980, 1982
Springfield Water, Light & Power	Dallman 3	Springfield, IL	Limestone	1980
Tampa Electric	Big Bend 4	Tampa, FL	Limestone	1985
Tennessee Valley Authority	Paradise 1, 2	Drakesboro, KY	Limestone	1983, 1983
Tennessee Valley Authority	Widows Creek 7	Bridgeport, AL	Limestone	1981
Tennessee Valley Authority	Widows Creek 8	Stevenson, AL	Limestone	1978

*Redesigned and rebuilt
**Wellman-Lord

Table 2
QUALITATIVE DEFINITION OF OPERATING ZONES

CODE	CHEMISTRY	MECHANICAL ENVIRONMENT	TEMPERATURE
Ⓐ	MILD CORROSIVE (VAPOR)	MILD	MILD
Ⓑ	MODERATE (IMMERSION)	MILD	MILD
Ⓒ	MODERATE	MODERATE	MILD
Ⓓ	MODERATE	SEVERE	MILD
Ⓔ	SEVERE	MILD	MODERATE
Ⓕ	SEVERE	MILD	SEVERE
Ⓖ	SEVERE	SEVERE	SEVERE
Ⓗ	MODERATE	SEVERE	MODERATE

Source: ASTM STP 837

Table 3
QUANTIFICATION OF OPERATING ZONES

	CHEMISTRY	MECHANICAL ENVIRONMENT (ABRASION LEVEL)	TEMPERATURE
MILD	pH 3-8 H_2SO_4	AGITATED TANK, WALLS, DUCTS, THICKENER	AMBIENT TO 150°F
MODERATE	pH 0.1-3 8-13.9 H_2SO_4 0-15%	SPRAY ZONE TANK BOTTOMS	AMBIENT TO 200°F
SEVERE	pH <0.1 >13.9 H_2SO_4 15%	HI ENERGY VENTURI IMPINGEMENT-TURNING VANES, TARGETS	AMBIENT TO 360°F

Source: ASTM STP 837

Table 4
COMPOSITION OF REPRESENTATIVE ALLOY MATERIALS

		Nominal composition, wt. percent								
UNS N°	Alloy	Ni	Mo	Cr	Fe	Cu	W	Cb	Co	C, max.
S31603	Type 316L	12.0	2.5*	17.0	Bal.	—	—	—	—	0.03
S31703	Type 317L	13.0	3.5	19.0	Bal.	—	—	—	—	0.03
S31725	Type 317LM	15.0	4.5	19.0	Bal.	—	—	—	—	0.03
N08904	Alloy 904L	25.0	5.0	21.0	Bal.	2.0	—	—	—	0.02
N06007	Alloy G	22.0	7.0	44.0	Bal.	2.0	1.0	2.0	—	0.03
N06985	Alloy G-3	22.0	7.0	44.0	19.5	2.0	1.5	—	5.0	0.015
N10276	Alloy C-276	16.0	16.0	56.0	Bal.	—	3.5	—	2.5	0.01
N06625	Alloy 625	22.0	9.0	61.0	3.0	—	—	4.0	—	0.05
N06022	Alloy C-22	22.0	13.0	58.0	3.0	—	3.0	—	2.5	0.01
N08700	Jessop JS700	21.0	4.6	25.0	Bal.	0.5	—	—	—	0.04

*High-molybdenum Type 316L has 2.75 per cent Mo, minimum