Construction Materials for Wet Scrubbers

Volume 1

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Prepared by
Battelle, Columbus Laboratories
Columbus, Ohio

ELECTRIC POWER RESEARCH INSTITUTE

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Research Project 982-14

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ABSTRACT

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

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

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

EPRI PERSPECTIVE

PROJECT DESCRIPTION

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

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

PROJECT OBJECTIVES

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

PROJECT RESULTS

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

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

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

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

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BACKGROUND

Flue gas desulfurization (FGD) is emerging as a very important part of the technology which will enable the United States to meet its future energy needs in an environmentally acceptable manner. FGD is the most advanced technology and clearly will be used in many electrical utility plants. Among the FGD processes, limestone and lime scrubbing are the most developed. Some of the major problems which have plagued the operation of these processes to date have been related to materials of construction for the various system components.

A variety of construction materials have been used in the full-scale lime/limestone FGD facilities that have been built to date. These materials can be classified as follows:

- Metals
- Organic linings and plastics
- Ceramic and inorganic materials.

Metals have been used in most components of FGD systems. Unlined carbon steel or high strength, low alloy steel such as Cor-Ten can be utilized where alkaline ($pH > 7$) conditions are maintained, such as in lime/limestone storage silos or in the piping that carries makeup slurry to the absorber section of the system, or where the metal is protected by a lining. Where unlined metal is exposed to sulfurous and sulfuric acids, either condensed from the gas stream or as part of an acidic slurry, corrosion-resistant alloys are required. A large amount of Type 316L stainless steel has been used in FGD system components such as prescrubbers, absorbers, spray nozzles, reheaters, and dampers. Moderate use has been made of Inconel 625 and Hastelloy G in critical locations such as outlet ducts, outlet dampers, and reheaters. When failure occurs, it is usually by general corrosion, pitting, or stress-corrosion cracking.

Organic linings have been used extensively in various components of flue gas desulfurization systems including prescrubbers, absorbers, outlet ducts, stacks, and tanks. They are attractive because their use to protect carbon steel provides the lowest price suitable materials choice for many of these components. While rubber is one of the forms of organic lining it is generally placed in a separate category because it is applied in sheets rather than in liquid form. In order to provide an effective barrier, the organic linings used in FGD systems are applied much more thickly than typical coatings. Moreover, the linings generally contain a flake-type filler which decreases the permeability of the film and provides reinforcement. In components such as venturi prescrubbers where high abrasion resistance is required, organic linings reinforced with glass cloth or inert matting have been used. These linings are applied to a nominal thickness of 1/8-inch (3 mm) and may contain special abrasion-resistant fillers such as alumina to improve wear resistance. Failure of organic linings can occur by blistering, debonding, wear from abrasive slurries, and temperature excursions.

Nonmetallic inorganic materials are used in prescrubbers, spray nozzles, slurry pumps, outlet ducts, bypass ducts, and stacks of FGD systems. The materials utilized include prefired bricks and shapes, hydraulic bonded concretes and mortars, and chemically bonded concretes and mortars, all of which are used as linings where temperature resistance, chemical resistance, and/or abrasion resistance are required. Prefired shapes are also used for spray nozzles and pump components. Acid-resistant bricks (ARB) are commonly used construction materials for stack linings. Alumina (Al_2O_3) bricks are more abrasion-resistant than acid-resistant bricks and will also withstand hot sulfuric acid conditions so that they have been used to line venturi throats. Silicon carbide (SiC) shapes have high abrasion and chemical resistance and are used for spray nozzles and pump components, as well as for lining venturi throats. Prefired bricks and shapes will resist service conditions that occur in FGD systems, but mortar failures can cause collapse of a lining constructed of prefired materials. Design aspects which could cause failure include mechanical stresses from shrinkage, insufficient thermal expansion allowances, mechanical attachment system, vibration, and/or thermal or mechanical shock.

Hydraulic-setting, cement-bonded concretes (hydraulic concretes) are commonly used as prescrubber, outlet duct, and stack lining materials in FGD systems. They contain calcium aluminate which can withstand temperatures of 500°F (260°C) without strength degradation. However, in strong sulfuric acid solutions (pH below 4) the calcium aluminate cements are attacked by a solution mechanism. If condensation occurs, and the pH of the attacking solution becomes low enough, failures by bond solution might be expected, resulting in the loosening of the aggregate and erosive wear of the lining.

Chemically bonded mortars are commonly used to bond ARB stack linings. Chemically bonded concrete mixes can be used as linings. They generally contain siliceous aggregates, a sodium silicate, potassium silicate, or colloidal silica bond phase, and a silicofluoride, phosphate, or organic bond gelling agent (like chemically bonded mortars). Since chemically bonded concretes can withstand hot acidic environments, they offer an abrasion-resistant alternative to organic linings. However, they have a finite permeability (and may crack), so any condensed acid may ultimately reach the substrate to which they are applied.

COMPONENTS WITH MAJOR MATERIALS PROBLEMS

The major materials problems are occurring with outlet ducts and stack linings. The outlet duct carries the flue gas from the absorber to the stack and is thus exposed to saturated (wet) flue gas at about 125°F (52°C) and/or reheated flue gas depending upon the existence and location of the reheater. Part of the outlet duct may also be exposed to hot flue gas (about 300°F; 149°C) during periods of shutdown if the FGD system has a bypass duct which joins the outlet duct ahead of the stack. The outlet duct has been a major problem area, particularly for units which have duct sections which handle both hot gas and wet gas. These sections are for the most part downstream from the bypass junction on units which do not have reheat. Acidic conditions developed during scrubber operation become more severe on bypass as the temperature is raised and other corrosive species in the unscrubbed flue gas (chloride and fluoride) are introduced.

Units which have outlet duct sections exposed only to wet gas predominantly use organic linings to protect the carbon (or Cor-Ten) steel structure. There have been some lining failures, but for the most part the organics are providing several years of service both for high sulfur and low sulfur coals. Some representative operating lives thus far (operation is continuing) are 6-1/2 years for a glass flake-filled polyester (Flakeline 103) at Phillips, 2-1/2 years for an inert flake-filled vinyl ester (Plasite 4005) at Cane Run 4, and 8 years for a mat-reinforced epoxy phenolic (Plasite 7122H) at Will County. The use of fluoroelastomer linings at Apache and Tombigbee is too recent to judge their performance.

Units which have duct sections which handle both wet gas and hot gas have experienced failure of organic linings. At Duck Creek and Conesville, the mica flake-filled polyester linings (Flakeline 151) in the stack breechings both failed under bypass conditions before scrubber start-up. The lining was replaced with Hastelloy G at Duck Creek and with a chemically bonded concrete lining (Sauereisen No. 54) at Conesville. The replacements have performed satisfactorily thus far for 3-1/2 years in both cases.

Stations which have outlet duct sections exposed only to reheated gas have had a good record of materials performance, as no problems were reported except in one special case. In as much as unlined carbon and Cor-Ten steels are giving service lives of 6-1/2 to 8 years thus far for both high sulfur and low sulfur coal units (La Cygne and Will County), it is quite likely that organic or inorganic linings may not be required for this type of environment except as a precautionary measure.

Outlet duct sections which handle both reheated gas and hot gas have less problems than those which handle wet gas and hot gas, but a few problems have occurred. Severe corrosion problems were experienced with the carbon steel outlet ducts of the old Lawrence 4 and 5 units which at one time burned high sulfur Kansas coal. However, carbon steel and Cor-Ten steel have been used successfully for more than 7 years thus far at Paddy's Run and Will County, respectively. Better performance may be attributable to a higher temperature rise provided by the reheat system and a lower sulfur oxides concentration in the flue gas exiting the absorber. Therefore, it is difficult to determine if linings are needed for this type of environment. Organic linings in use for this service with no problems reported include fluoroelastomers for 1-1/2 years at Tombigbee (CXL-2000), for 1 year at Apache 2 (CXL-2000), and recently installed at Apache 3 (Flakeline 282-X), a glass flake-filled polyester for 2-1/2 years at Milton R. Young (Flakeline 103), and an inert flake-filled vinyl ester for 1-1/2 years at Cholla 2 (Plasite 4030). Inorganic linings (hydraulic bonded concretes) are used successfully thus far for this service for 7 years at Hawthorn (gunite), for 3-1/2 years at Cane Run 4 (Pre-Krete G-8), and for 1-1/2 years at Huntington (Pre-Krete G-8).

The flue gas from an FGD system exits to the atmosphere through a chimney or stack. The stack consists of an outer shell constructed of concrete or carbon steel and one or more flues constructed of brick or metal which carry the flue gas. The interior surface of the flue is subjected to the flue gas conditions and therefore provisions must be made for protection against corrosion. These provisions include the use of corrosion resistant materials or linings and/or the use of stack gas reheat to prevent condensation.

The performance of a stack lining depends on whether the scrubbed gas is delivered to the stack wet or reheated, and whether or not the stack is also used for hot bypassed gas. These factors appear to have a stronger effect on the performance of lining materials than differences in fuel sulfur, application techniques (e.g., surface preparation or priming), operating procedures (e.g., thermal shock), design aspects (e.g., annulus pressurization), and other factors which can affect performance.

Acid-resistant brick linings have exhibited good performance regardless of operating conditions. However, in spite of their successful background they have two limitations: (1) acid penetration of the brick, mortar, or brick-mortar interface may occur under wet conditions, and (2) they may not be suitable linings in earthquake-prone areas. It remains to be seen whether pressurization of the stack annulus can solve the penetration problem under wet conditions.

Hydraulic cement bonded concretes (Pre-Krete G-8 and Haydite/ Lumnite mixes) have been successfully used under dry conditions for up to 8 years with high sulfur fuel, and have given over one year of service under wet conditions at Green River. Chemically bonded mixes containing silicate binders (such as Sauereisen No. 33) are generally considered to be more acid-resistant than hydraulic cement, yet none are in use under high sulfur coal environments. One limitation of the inorganic concretes is that the weight penalty of relatively thick (1-1/2 inch; 38 mm) linings could make them unsuitable for use on steel flues designed for organic linings. However, inorganic mixes have been used directly against the steel shell in both new Lawrence stations, and in at least one new station now under construction, so they provide a high temperature material alternative to acid-resistant brick. Since inorganic mixes are commonly anchored to the shell, and can be reinforced with chopped steel fibers, they may be more suitable for use in seismic areas than acid-resistant brick. The only other limitation of these materials is the risk of substrate corrosion in the event of acid condensation. Although even cracked material will provide a physical barrier to minimize acid transport to the substrate, a membrane backing or other means of providing secondary substrate protection would be desirable.

Organic linings used to date have been based primarily on polyester or vinyl ester resin binders, both of which have deteriorated under some type of flue gas operating condition with high sulfur fuel, and commonly on bypass. Resins more resistant to the 300°F (149°C) bypass temperatures and hot acidic conditions appear to be needed if longer life is to be obtained. The fluoroelastomer linings (CXL-2000 and Flakeline 282-X) now appearing in the newer stacks may provide a significant improvement in the performance record of organic linings. Whether the new materials will be able to provide reasonable service lives in hot and wet environments typical of many high sulfur fuel stacks remains to be seen.

High nickel alloys are being seriously considered as liners for wet stack applications by several utilities, so as to avoid loss of generating capacity from unplanned stack failures. These alloys are already being used in the stack breeching area of outlet ducts, and in the bypass duct downstream of the exit damper. One installation with a high nickel alloy stack lining is in the early stages of start-up. However, these alloys are as yet unproven under stack conditions that cycle between wet gas and hot gas.

Outlet ducts and stacks are critical components in that failures may require complete boiler shutdown and loss of generating capacity for lengthy periods due to the lack of standby components or bypass capability. Research efforts for these components need to be directed to:

1. Compiling and maintaining general materials performance data
2. Characterizing environmental conditions where failures are occurring
3. Post-testing materials exposed to FGD environments to determine and/or verify failure mechanisms
4. Laboratory testing of commercial materials to verify property data, and
5. Developing new or improved materials and design concepts based on the above information.

COMPONENTS WITH MODERATE MATERIALS PROBLEMS

A moderate amount of materials problems is occurring with prescrubbers, absorbers, reheaters, dampers, pumps, and piping and valves. Prescrubbers cool the flue gas from the air preheater exit temperature (about 300°F; 149°C) to the adiabatic saturation temperature about 125°F; 52°C). There are basically two types of prescrubbers: (1) a quench or saturation duct with water sprays which cools hot gas already cleaned of particulates by an electrostatic precipitator, and (2) rod, constricted throat, plumb bob, or flooded disc (all usually variable throat) venturi systems which cool the gas and remove particulates.

Lime/limestone scrubbing liquor is usually used in the prescrubber so that it operates at a pH of about 4 to 6. In some cases, makeup water or reclaimed water is used in quench or saturation ducts which means that the operating pH is about 1 to 3. The low pH exit liquor from a quench or saturation duct is sent to the SO_2 absorber to be mixed with the lime/limestone scrubbing liquor. Most of the chloride in the flue gas is removed in the prescrubber but the chloride content of the exit liquor depends upon the chloride content of the coal and the water balance for the FGD system.

Quench ducts are usually constructed of either concrete-lined steel or Carpenter 20 alloy. The longest continuing operating experience thus far with hydraulic bonded concrete (Pre-Krete G-8) is more than 3-1/2 years at Cane Run 4 and with Carpenter 20 is more than 3 years at Conesville. Materials problems were reported for only two units, Petersburg and Southwest, both of which use Pre-Krete G-8 linings. The failures may be related to acidic environmental conditions in these cases since thickener overflow, rather than limestone slurry, is used as the feed liquor to the quench duct. Without the presence of limestone, this liquor can become fairly acidic ($pH < 3$) due to absorption of SO_x and HCl from the flue gas. Southwest has replaced the Pre-Krete lining with a Uddeholm 904L lining over the carbon steel. The alloy lining is in good condition after more than 2 years of service. Petersburg is planning either to reline the quench duct with a chemically bonded concrete (Sauereisen No. 72) or to use a high alloy.

The hot, wet, erosive environment of venturi prescrubbers requires the use of erosion resistant materials. Venturi prescrubbers are constructed of lined carbon steel or unlined alloys. Organic lining materials used to date in prescrubbers appear to have failed by erosion when unprotected, but appear to be providing corrosion protection when covered with erosion-resistant ceramic materials. An organic lining covered with hydraulic bonded concrete (Kaocrete HS over Plasite 7122) has been used successfully for more than 6-1/2 and 8 years thus far at La Cygne and Will County, respectively. Organic linings covered with prefired ceramic bricks are used in the throat areas of several venturis. There is insufficient operating time to distinguish between the performance of Al_2O_3 and SiC bricks, both of which should provide long service. Alloys have performed quite well in venturi prescrubbers except where chloride attack is a problem. The 2,000 ppm chloride content in the Cholla 1 system has caused rapid attack by pitting and stress corrosion of the Type 316L stainless steel vessel. The chloride attack problem of Type 316L stainless steel at low pH levels is leading to the selection of more chloride-resistant alloys such as Type 317L stainless steel, Uddeholm 904L, Incoloy 825, and others for prescrubbers in FGD systems now in the design and construction stage.

The flue gas enters the absorber from an inlet duct (or directly from a prescrubber) at either about 125°F (52°C) or about 300°F (149°C) depending upon whether or not there is a prescrubber. The flue gas exits the absorber to an outlet duct at the adiabatic saturation temperature of the gas (about 125°F; 52°C). The conditions in the absorber are similar to those in prescrubbers where lime/limestone scrubbing liquor is used, i.e., pH of 4.5 to 6.5. The chloride content of the scrubbing liquor depends upon how the prescrubber and absorber loops are tied together.

Absorbers used for desulfurization of flue gas incorporate a variety of designs and many different materials of construction. Almost every absorber incorporates a combination of materials, but the major materials categories used in construction are stainless steel, rubber-lined carbon steel, organic-lined carbon steel, and ceramic-lined carbon steel.

Stainless steel (Type 316L) construction has been the choice for the absorbers at Cholla 1, Duck Creek, La Cygne, and the new systems at Lawrence 4 and 5, as well as a section of the absorber vessel at Green River. Type 316L stainless steel components such as trays, plates, supports, and fasteners have been used in many other absorbers. High chlorides can present a corrosion problem, and abrasion by scrubber slurries can sometimes cause wear failures. The operating experience thus far ranges from 1-1/2 years at Lawrence (Unit 5) to 6-1/2 years at La Cygne; both units are still in service although some patches have been made in the stainless steel sidewalls of the new absorbers at Lawrence. The only problems reported were at Cholla 1 where corrosion and pitting of the stainless steel occurred because of the relatively high chloride content (2,000 ppm) of the scrubbing liquor. Areas in the bottom of the absorbers were repaired by lining with an epoxy (Coroline 505AR), but the lining has exhibited erosion and debonding.

The absorbers at Conesville, Petersburg, Southwest, and Widows Creek are constructed primarily of neoprene-lined steel, while the absorbers at Will County and Winyah are constructed primarily of natural rubber-lined steel. At Conesville, incorrect lapping in an area of one absorber caused problems until the lining was replaced with proper lapping. After 7,000 hours of operation at Widows Creek, the neoprene lining in the tapered hopper bottom portion of the absorbers debonded and was replaced with a Type 316L stainless steel liner. Also, sparks from a welder's torch have caused the neoprene lining to catch fire at Conesville and Widows Creek. The longest operating experience thus far has been about 8 years at Will County where the linings are still in service.

Several absorbers are in operation with their original organic linings which include mica and glass flake-filled polyesters and mat-reinforced linings. The only problems reported were at Sherburne 1 where some patching of the mica flake lining (Flakeline 151) was required, Milton R. Young where some repair of the glass flake lining (Flakeline 103) was required in the areas of spray impingement, and R. D. Morrow where there have been spot failures of the glass flake lining (Protecto-Flake 550) and several pinhole leaks have developed in the absorber wall. The longest period of successful performance thus far is at Paddy's Run where a glass flake lining (Flakeline 103) has experienced more than 22,000 hours of actual operating time and is still in service.

While linings have been used in many absorbers, the time in service in most instances has been too short to obtain an effective appraisal of their performance. From the information available at present, certain conclusions are possible regarding the use of organic linings. They are as follows:

- A high-quality lining material should be selected. The minimum quality of lining used in absorbers should be (a) the trowel-applied, glass flake/polyester of 80 mil (2 mm) nominal thickness in areas subject to normal abrasion, and (b) the heavy duty (1/8-inch nominal thickness; 3 mm) fiber mat- reinforced materials containing abrasion-resistant fillers in the high-abrasion areas (wherever slurry is projected against the lining).
- The lining material must be applied by skilled, experienced applicators who will stand by their work.
- The applicator must understand metal surface preparation procedures and employ them properly.
- Careful quality control procedures must be used.

Although very few absorbers have been constructed of ceramic-lined carbon steel, many have used some type of inorganic material at specific high-abrasion areas such as venturi throats and sumps. The absorbers at Cane Run 4 and Mill Creek have hydraulic bonded concrete (Pre-Krete G-8) linings, while the absorber at Green River is lined with this material (Pre-Krete G-8) below the mobile bed and above the mist eliminator. Generally, good performance has been reported for the inorganic concrete linings. However, the experience is too limited in most instances to draw reliable conclusions regarding long-term performance and amount of maintenance required.

The flue gas leaving the absorber unit of an FGD system can be reheated to avoid acid condensation in the stack and to provide buoyancy and low visibility for the plume, or it can be left at the scrubber exit temperature. When reheat is chosen, it has been done by: (1) providing a heat exchanger in the flue gas stream, (2) heating air externally and injecting it into the flue gas, (3) direct combustion at the outlet duct, or (4) bypassing some unscrubbed flue gas and mixing it with the scrubbed gas. Reheaters provide a temperature rise in the range of 20° to 75°F (11° to 42°C) for the scrubbed flue gas.

If an in-line reheater is used, it is installed in the absorber vessel or flue gas duct after the mist eliminator, and the heat can be supplied by steam or hot water. The materials of construction for the tubes or coils range from carbon steel to Inconel 625. Finned carbon steel tubes containing hot water under pressure have been used for reheat at old and new Lawrence 4 and 5, Sherburne, and Hawthorn. The same type of tubes are used with steam at Cane Run 5. Some tube failures (general corrosion) occurred at Lawrence after 6 years of operation, but after switching to low sulfur coal there have been no serious problems, presumably because of less sulfur oxides in the scrubbed flue gas. At Sherburne, which also burns low sulfur coal, four weld failures occurred early in the operation because of excessive stress. Only infrequent leaks (corrosion mechanism is unknown) have occurred during the past 3-1/2 years since the stress was removed. Corrosion problems after 1-1/2 years of operation required replacement of some tubing at the 180 degree bends at Cane Run 5. Leaks (corrosion mechanism is unknown) occurred at the tubing welds at this installation which burns high sulfur coal, and consideration is being given to using a more corrosion-resistant material for the reheater tubes.

When the heat is supplied by hot water, the inside tube wall temperature is relatively low (230° to 350°F; 110° to 177°C), while with steam, the wall temperature is in the range of 450° to 650°F (232° to 343°C). Carbon steel tubes may be more resistant to general corrosion in a hot water system than in a steam system because of the lower tube temperature in the case of the former. The rate of corrosion generally increases as the surface temperature increases at constant acid concentration. Perhaps for this reason, alloy tubes are usually used when the heat is supplied by steam.

At Will County, steam in smooth tubes is used for reheat. The top tube banks were originally Cor-Ten steel and the bottom Type 304L stainless steel. Leaks developed in 6 months and the tube banks were replaced with carbon steel and Type 316L stainless steel, respectively. Pinhole attack on the carbon steel requires tube replacement every year, and stress-corrosion cracking of the stainless steel, every 1-1/2 years. Smooth Type 316L stainless steel tubes containing steam are also used for reheat at Cholla 1 and La Cygne. At the former installation, the tubes need replacement after 6 years of operation because of corrosion. At the latter installation, the tubes are a replacement for Type 304 stainless steel which failed because of corrosion, but the Type 316L lasts for only 2 to 3 years. Inconel 625 tubes with Uddeholm 904L baffles are used at Cholla 2, and Hastelloy G and Inconel 625 plate coils are used at Colstrip without any corrosion problems after 1-1/2 and 4 years, respectively.

In the indirect method of reheat, air is heated separately from the scrubber system, and the corrosion and fouling problems are circumvented. Carbon steel steam coils are used at Petersburg, Widows Creek (tubes have copper fins), and Huntington (also has bypass reheat) without any materials problems. The longest operating experience thus far is 2-1/2 years at Widows Creek where operation is continuing.

For direct combustion reheat, oil or gas is burned and the combustion product gas is mixed with the scrubbed flue gas to raise its temperature. Oil burners outside the outlet duct have been installed at Cane Run 4, Elrama, Phillips, and Bruce Mansfield; however, they have been removed or abandoned at the latter three locations. The problems included flame instability, burner corrosion, refractory lining failure, and poor mixing.

Dampers are used in the ductwork of FGD systems for isolation of sections or components from the flue gas and for control of the flue gas flow rate. Three types of dampers are in use, namely louver, guillotine, and butterfly. Mechanical problems with dampers, caused by deposition of solids from the flue gas, have outweighed any materials problems. However, corrosion and erosion do occur. Dampers are utilized in three locations: on the inlet duct to the scrubber, the outlet duct from the scrubber, and the bypass duct which goes directly from the air preheater or dry particulate collector to the stack.

The inlet dampers used on the lime/limestone systems are about evenly divided between guillotine and louver type, with a few butterfly dampers in use. Because the inlet dampers are subjected to the hot, relatively dry flue gases ahead of the scrubber, it is possible to utilize unlined carbon steel in this location. This material is used at several of the sites, particularly those where low sulfur coal is burned and the sulfur oxide concentrations are relatively low. However, the damper seals usually are an alloy such as Type 316L stainless steel, Hastelloy G, or Inconel 625. The only plants citing corrosion of carbon steel inlet dampers were Phillips and the original installations at Lawrence, both of which were burning high sulfur coal at the time. In spite of the hot, relatively dry conditions at the inlet, most of the systems have inlet dampers constructed of Cor-Ten steel or clad with stainless steel in order to avoid possible corrosion. Type 316L stainless steel inlet dampers have operated at Cholla 1 for 6 years and at Bruce Mansfield for 3-1/2 years without any problems thus far.

The dampers on the scrubber outlet are subject to the wet flue gas and for this reason greater use has been made of stainless steels, either as a cladding or for the entire construction. Duck Creek has Hastelloy G for the outlet damper, and Conesville uses Inconel 625. Type 316L stainless steel at Southwest corroded badly in 3 months as a result of high chloride concentrations and was replaced with a Uddeholm 904L frame, Inconel 625 seals, and Hastelloy C fasteners. The replacement is satisfactory after more than one year of service. Where bypass dampers are used, they are usually constructed of the same materials as the outlet damper because they can be exposed to the wet flue gas.

Pumps are used for a variety of services in FGD systems such as slurry feed to the prescrubber and absorber spray headers, slurry transfer, sludge transfer, clear water transfer, and clear liquor feed to the mist eliminator wash nozzles. Rubber-lined centrifugal pumps are commonly used for moving slurries with generally satisfactory results. Ordinary carbon steel pumps are usually used for clear water transfer. Stainless steel pumps also find substantial usage, especially where only small pumps are required. The experience with pumps has varied widely in the different desulfurization units. Some plant representatives reported that pumps have given little problem, while others cited slurry feed pumps as their most pressing problems in keeping their units on stream. The reasons for these differences are not obvious in all cases, but some pump manufacturers have had noticeably more success than others. Some of the causes for failure of rubber linings are:

- Poor quality lining
- Foreign objects in slurry which cause mechanical damage
- Cavitation because of dry operation
- A particularly abrasive slurry with large particles
- Overworking the pump (operating too near maximum capacity)
- Use of undersized pumps.

At Cane Run 4, rubber debonding failures on the rotors were caused by overloading and too high a tip speed; also erosion of the housing linings has occurred. The linings were replaced and the pumps were slowed down. The rubber linings have failed on all ten of the absorber feed pumps at Mill Creek. At Green River, the housing linings have torn loose from the absorber feed pumps, and the impeller linings have eroded from slurry wear and insufficient curing of the rubber. The French-made linings have been replaced twice and this installation is now successfully using Ni-Hard impellers without linings. The rubber-lined pumps for prescrubber feed, absorber feed, and slurry transfer at Will County have been in service for more than 8 years thus far and have not given any materials problems.

The Duquesne Light Company has studied pump materials fairly extensively at Phillips Station. Their initial selection of a Carpenter 20 steel pump with no lining was based on a 2-year performance guarantee rather than on a preconceived idea that rubber-lined pumps would not withstand the pressure head required for the absorber feed. However, the impellers lasted only about 200 hours. Rather than replace the pumps with rubber-lined pumps, which would be very costly, a search was made for alternative materials for impellers and for use as wear rings in the original pumps. The replacement materials included Type 317 stainless steel, titanium, 20 percent chrome-iron, and CD-4MCu. Impellers made from the best materials would last about 2,500 to 3,500 hours and could not be rebuilt. A rubber-lined pump tried at Elrama looked good so a change may be made to rubber-lined pumps sometime in the future.

The piping used in FGD systems is required to handle alkaline makeup slurry, recycle and discharge slurry, and reclaimed water. The type of material selected depends to a large extent on the type of service encountered. The piping that handles the recycle slurry is subjected to the most severe service conditions, while the piping that handles the alkaline makeup slurry does not require the acid resistance that is needed for the recycle or discharge lines. The reclaimed water piping is not subjected to the erosive conditions encountered with slurries. The piping used in FGD systems is predominantly rubber-lined carbon steel which is selected for its erosion and corrosion protection capabilities. However, significant amounts of fiberglass-reinforced plastic (FRP) and Type 316L stainless steel are utilized as well.

Rubber-lined carbon steel is most commonly used to deliver the alkaline makeup slurry, and this material has provided generally good service. Synthetic rubber lining appears to be giving better service than natural rubber in this application. The longest operating life has been at Will County where the reducers eroded and were replaced after 6 or 7 years. Unlined carbon steel has been used to carry the alkaline makeup slurry without encountering erosion problems at several of the lime scrubbing installations including 6-1/2 years of operation thus far at Phillips. FRP has been used at a few sites, but has suffered from erosion at Cholla 1, Duck Creek, and Cane Run 4, and joint failure at Southwest. Use has been made of Type 316L stainless steel to carry the makeup slurry at Green River and there have been no problems after 4-1/2 years of operation.

The slurry recycle and discharge lines are either rubber-lined carbon steel or FRP. Problems similar to those encountered on the makeup slurry lines have occurred. Debonding of the rubber lining occurred at Widows Creek and erosion of the lining occurred at Sherburne. At the latter installation, FRP is being used to replace the rubber-lined carbon steel.

The reclaimed water piping, which carries less solids, has been made of FRP at the majority of the locations. A few cases of failure of the FRP piping at joints have been reported, but results in general have been good. A water hammer broke some of the FRP pipe at Conesville and Bruce Mansfield. Flanged or shop fabricated joints are preferable to field-cemented joints because pipefitters are not skilled in making FRP joints. Where carbon steel piping is used in this application, it is about equally divided between unlined and rubber-lined. No problems have been reported for these materials.

The materials chosen for the spray headers which are located inside prescrubbers and absorbers are primarily Type 316L stainless steel and FRP, with each having about the same amount of usage. No difficulties were reported for FRP in this service, but Type 316L stainless steel underwent erosion in the venturi at Widows Creek. Rubber-lined and clad carbon steel has been used successfully at six stations including La Cygne, where the spray headers have been in operation for more than 6-1/2 years thus far.

Valves are used in FGD systems for isolation and control functions. Valve problems are generally not materials related but plugging and mechanical problems have frequently occurred. As a consequence, there seems to be a consensus that the number of valves in the system should be kept to a minimum. Rubber-lined valves are the most common, although many stainless steel valves are used. Four types of valves are employed: knifegate, plug, pinch, and butterfly.

Type 316L stainless steel knifegate valves have been used for isolation functions, especially at high pressures where metal is required. However, FRP has been utilized for low pressure service. Although leakage tends to be a problem, there have been no reports of serious corrosion of stainless steel knifegate valves.

Rubber-lined plug valves have also been used for isolation functions and have encountered erosive wear at six stations. All but one of these stations (Southwest) have considerable amounts of fly ash in the recirculating slurry. These valves have been used successfully at six stations, all of which have electrostatic precipitators for fly ash removal except for Cholla 2. The reason for the successful operation at Cholla 2, where the scrubbing liquor contains fly ash, is not known. Rubber-lined plug valves have been successfully replaced with pinch valves at Colstrip, where they have been in service for about 3 years thus far, and at Duck Creek. At the latter site, the valves were replaced because of operating problems rather than erosion. Butterfly valves with rubber linings have been used for isolation applications at only a few sites, and no problems have occurred with them.

For control functions, rubber-lined plug valves have had erosion problems. Rubber pinch valves have been successful but periodic liner replacement is required when they are subjected to high velocity flow. Rubber-lined butterfly valves and Type 316L stainless steel knifegate valves appear to be giving satisfactory performance where they have been used for flow control. An exception is at La Cygne where stainless steel knifegate valves have an average lifetime of only one year. The problem is erosion caused by the scrubbing slurry, which contains 27 percent solids, when the valves are partially closed to control the flow. At Phillips and Colstrip, eroded rubber-lined plug valves have been successfully replaced with rubber pinch valves. However, at Will County, the original rubber pinch valves on the spent slurry line lasted only 250 hours and were successfully replaced with butterfly valves.

Prescrubbers, absorbers, reheaters, dampers, pumps, and piping and valves are of moderate importance due to the size of the component, difficulty of repair, availability of materials, or the lack of a standby unit or bypass capability. Moderate research efforts appear desirable to identify materials failure mechanisms, important environmental factors, and proper design techniques. However, much of this type of information can be developed by post-testing full-scale components, correlating failures with the service environment, and disseminating this information to the industry in the form of a newsletter.

COST INFORMATION

Cost information was obtained from A&E firms, equipment suppliers, and materials suppliers. The following installed cost ratios were provided for absorber vessels:

Construction Material	Relative Cost
Glass flake/polyester-lined carbon steel	1.00
Rubber-lined carbon steel	1.15
Type 316L stainless steel	1.50

The installed cost of glass flake/polyester-lined carbon steel absorber vessels is about \$24/ft^2 (\$258/m^2). Typical installed costs for stack lining materials are:

	Installed Cost \$/ft^2	(\$/m^2)
Foam glass	15-20	(160-220)
Plain steel	18-30	(190-320)
Acid-resistant brick	25-60	(270-650)
Flakeglass lined steel	25-45	(270-480)
FRP	~35	(~380)
Inorganic concrete lined steel	30-50	(320-540)
Type 316/317 stainless steel	35-70	(380-750)
Fluoroelastomer lined steel	45-70	(480-750)
Inconel/Incoloy	90-125	(970-1,350)

However, initial installed costs are only one criterion which may affect the selection of a material. The other factors are design aspects (amount of chloride in coal, earthquake zone, etc.), estimated service life, maintenance costs, and the cost of lost power production associated with any repair or replacement required. In order to take all these factors into account, it is necessary to perform a present worth analysis for various materials in a specific FGD component. However, it is difficult, if not impossible, to determine service life and maintenance costs without many years of operating experience for each material under consideration.

RECOMMENDATIONS

The utility industry appears to suffer from the lack of a centralized source of information on materials for FGD system components. A coordinated plan of documenting materials quality as it is installed (new or repairs), monitoring performance and operating conditions, and then post-testing materials to determine failure mechanisms appears highly desirable. This is now done to a limited extent for metals by FGD system suppliers and/or metal companies but little attention has been given to organic and inorganic materials. Research programs are needed on the development of inexpensive materials and methods for lining or protecting outlet ducts and stacks. Experiments should be performed to determine the effect of additives such as magnesium on the corrosiveness of lime and limestone slurries on metals at various pH's and chloride concentrations, especially with regard to closed-loop operation.

Section 1

INTRODUCTION

Flue gas desulfurization (FGD) is emerging as a very important part of the technology which will enable the United States to meet its future energy needs in an environmentally acceptable manner. As a method to allow use of coal in an environmentally acceptable manner, FGD is the most advanced technology and clearly will be used in many electrical utility plants.

Among the FGD processes, limestone and lime scrubbing are the most developed. Over 35 full-scale installations using limestone or lime scrubbing are now in operation. Some of the major problems which have plagued the operation of these systems to date have been related to materials of construction for the various system components. The service conditions in a wet FGD system present some challenging materials problems. The materials selected must protect the pumps, piping, scrubber internals, stack liner, etc., from corrosion and/or erosion. Alloys, linings, plastics, and ceramics have been tried with varying degrees of success.

Materials failures in FGD systems have resulted from a variety of causes, such as corrosion, erosion, and lining failure due to poor application or to high temperature excursions. Numerous test coupon studies have been performed in FGD systems as an aid in determining suitable construction materials for various services. However, the validity and value of the results from these tests is somewhat in doubt because of general questions concerning the representativeness of the environment and the small size of the coupons (particularly for lined coupons). The amount of operating experience with full-scale limestone and lime FGD systems is approaching the point where it should be possible to obtain some valuable information on materials by carefully analyzing this experience. This report is a systematic documentation and analysis of the experience with materials of construction on full-scale limestone and lime scrubbing systems. It is not a guidelines document, but rather a summary of materials experience.

The information contained in this report is intended to aid utilities and FGD equipment suppliers in selecting materials of construction that will perform satisfactorily without unnecessary expense. This, in turn, should enhance the availability of FGD systems which are now required by law for most new coal-fired utility boilers in order to meet New Source Performance Standards.

OBJECTIVE

The objective of this program was to provide a comprehensive documentation and analysis of utility experience with materials of construction in full-scale lime/limestone wet flue gas desulfurization systems on boilers burning eastern or western coals. This was done through a combination of plant visits, other contacts with FGD system operators and equipment and materials suppliers, and literature searching.

METHODOLOGY FOR DATA COLLECTION

This program began with a literature search to find relevant information on experience with various materials in FGD systems. The literature search included machine searches of the following sources:

1. Pollution Abstracts
2. National Technical Information Service (NTIS)
3. Air Pollution Technical Information Center (APTIC)
4. Smithsonian Science Information Exchange (SSIE)
5. ERDA/RECON
6. BASIS 70
7. Chemical Abstracts.

Pollution Abstracts corresponds in coverage to the printed Pollution Abstracts publication from January, 1970 to the present. Domestic and non-U.S. reports, journals, contracts, patents, symposia, and government documents in the areas of pollution control and research are covered.

NTIS is a file containing citations and abstracts of government-sponsored research reports prepared by Federal agencies or their contractors from January, 1964 to the present. It corresponds to the Weekly Government Abstracts and the semimonthly Government Reports Announcements and is prepared by the U.S. Department of Commerce.

APTIC is a comprehensive data base on air pollution, its effects, prevention, and control. The file includes, but is not limited to, all abstracts in Air Pollution Abstracts and covers the period from 1966 to the present. APTIC is produced by the Manpower and Technical Information branch of the U.S. Environmental Protection Agency.

SSIE covers on-going and recently completed research projects in the life, physical, and social sciences. Current projects are included from over 1300 funding organizations, such as Federal, state, and local governments; nonprofit organizations; colleges and universities; some non-U.S. organizations and private industry.

The ERDA/RECON Energy Data Base began in 1974; however, it contains material dating back to the late 1800's. Examples of the broad categories included are: chemistry; coal; energy conservation, consumption, and utilization; energy conversion; and environmental sciences. Scientific and technical reports of the U.S. Department of Energy and its contractors, other government agencies, universities, industrial and research organizations are included in the data base, as well as books, conference proceedings, patents and journal literature. Selection is based solely on subject matter.

BASIS 70 is a data base established by the Battelle Energy Information Center (BEIC). It includes citations (over 17,500 in total) of all material on file at BEIC from 1935 to the present.

In addition to the machine searches, a search of Chemical Abstracts from 1965 to the present was conducted by hand. Also, the information on materials in previous Battelle FGD trip reports and in the files of the Stack Gas Emission Control Coordination Center was summarized. All of the pertinent references were compiled into a bibliography which appears at the end of this report.

Information on materials performance was collected from most of the full-scale lime/limestone FGD installations in operation, from most of the major equipment suppliers for such systems, and from several A&E firms. Wherever possible, the data was collected by site visits, since this method generally yields the most complete and up-to-date information. To supplement the visits, information was also obtained by telephone discussions and correspondence exchange. In addition, contacts were made with several companies which manufacture materials with potential application in FGD systems. A list of site visits and other contacts which yielded information for the trip reports that appear in the appendix to this report is included in Table 1-1. All of the trip reports were sent to the cognizant organizations for review.

BACKGROUND

There is a wide choice of equipment and systems currently available to help solve the problem of flue gas desulfurization (FGD) at power plants. With the high cost of installing any system, one must be sure to make the right choice the first time. A great many factors enter into the decision, and many trade-offs must be evaluated before the selection can be finalized. Generally speaking, some of the most important design criteria in the selection of any system or piece of equipment are:

1. Technical performance - does the unit consistently meet the specified SO_2 removal efficiency?

2. Reliability - what are its weaknesses and what can be done to protect against damage or failure?

3. Outage - how much of an outage can be tolerated without loss and how quickly can the unit be repaired or replaced?

4. Cost - what is the most cost effective system?

Every particular installation has its own peculiarities. Every situation must be analyzed carefully for the effect upon power plant operation. There is no trade-off in meeting technical performance standards, but the margin of safety can be weighed against the cost. Reliability can be traded off with cost, but the losses due to a failure could be much greater than an extra measure of reliability would cost. In many cases, a whole power plant may be forced to shut down if the FGD system fails.

In selecting materials of construction for an FGD system, one has to make a judgment on maximum corrosion rates that can be tolerated, i.e., how long the equipment will last under the conditions that exist, and how much of a problem there will be in restoring normal operation when wastage limits are reached. Actually, though some corrosion is inevitable, it is the combination of erosion with corrosion that may really cause damage. In addition, the potential exists for severe erosion problems stemming from the extensive handling of liquid/solid slurries and of gas streams containing particulate matter. In some portions of the system, these streams move at velocities sufficient to cause significant

Table 1-1

SOURCES OF INFORMATION FOR TRIP REPORTS ON CONSTRUCTION MATERIALS FOR WET SCRUBBERS[a]

Trip Number	Date of Visit	Site Visited	Persons Interviewed	Location
EPRI-CM1	11/28/78	Louisville Gas & Electric-Paddy's Run 6[b]	R. P. Van Ness	Louisville, KY
EPRI-CM2	11/28/78	Louisville Gas & Electric-Cane Run 4	R. P. Van Ness	Louisville, KY
EPRI-CM3	11/28/78	Louisville Gas & Electric-Mill Creek 3[b]	R. P. Van Ness	Louisville, KY
EPRI-CM4	11/28/78	Louisville Gas & Electric-Cane Run 5	R. P. Van Ness	Louisville, KY
EPRI-CM5	11/29/78	Kentucky Utilities-Green River	K. D. Cummins	Central City, KY
EPRI-CM6	11/30/78	Indianapolis Power & Light-Petersburg 3	Steve Moore & Rex Hoppes	Petersburg, IN
EPRI-CM7	12/7/78	Tennessee Valley Authority-Widows Creek 8	W. L. Wells	Bridgeport, AL
EPRI-CM8	12/19/78	Research-Cottrell	G. T. Paul	Somerville, NJ
EPRI-CM9	12/20/78	Chemico	A. Saleem & R. Helfant	New York, NY
EPRI-CM10	12/21/78	Combustion Equipment Associates	M. J. Kinkhbwala	New York, NY
EPRI-CM11	1/11/79	Columbus & Southern Ohio Electric-Conesville 5 & 6	Dan Boston	Conesville, OH
EPRI-CM12	1/26/79	Babcock & Wilcox	H. M. Majdeski	Barberton, OH
EPRI-CM13	2/14/79	Sauereisen Cements[c]	G. W. Read	Pittsburgh, PA
EPRI-CM14	2/20/79	Pocono Fabricators[c]	Dick Zerwey	East Stroudsberg, PA
EPRI-CM15	2/21/79	Pennsylvania Power-Bruce Mansfield 1 & 2	R. C. Forsythe	Shippingport, PA
EPRI-CM16	2/22/79	Duquesne Light-Phillips	J. M. Malone	South Heights, PA
EPRI-CM17	2/22/79	Duquesne Light-Elrama	J. M. Malone	Elrama, PA
EPRI-CM18	3/5/79	Dudick Corrosion-Proof	T. M. Dudick	Macedonia, OH
EPRI-CM19	3/5/79	Ceilcote	W. R. Slama	Berea, OH
EPRI-CM20	3/6/79	Rigiline	C. F. Overbeck	Brunswick, OH
EPRI-CM21	3/6/79	Corrosioneering	Dennis Newton	Grafton, OH
EPRI-CM22	3/16/79	UOP	P. S. Nolan	Darien, CT
EPRI-CM23	3/16/79	Peabody Process Systems	C. A. Johnson	Stamford, CT
EPRI-CM24	3/26/79	Commonwealth Edison-Will County 1	John Reid	Joliet, IL
EPRI-CM25	3/27/79	Central Illinois Light-Duck Creek	Kim Swahlstedt	Canton, IL
EPRI-CM26	3/28/79	Southern Illinois Power Coop.-Marion 4	Henry Niecamp	Marion, IL
EPRI-CM27	4/10/79	Montana Power-Colstrip 1 & 2	Robert Olmstead	Colstrip, MT
EPRI-CM28	4/11/79	Minnkota Power Coop.-Milton R. Young 2	Phil Richmond	Center, ND
EPRI-CM29	4/12/79	Northern States Power-Sherburne 1 & 2	Rickey Kruger	Becker, MN
EPRI-CM30	4/23/79	Black & Veatch	Don Swenson	Overland Park, KS
EPRI-CM31	4/24/79	Kansas City Power & Light-Hawthorn 3 & 4	Ralph Boehm	Kansas City MO
EPRI-CM32	4/24/79	Kansas Power & Light-Lawrence 4 & 5	Ron Teeter	Lawrence, KS
EPRI-CM33	4/25/79	Kansas City Power & Light-La Cygne 1	Terry Eaton & Dale Feuerborn	La Cygne, KS
EPRI-CM34	4/26/79	Springfield City Utilities-Southwest 1	Bryan Brooker	Springfield, MO
EPRI-CM35	5/23/79	Environeering	Hal Taylor	Schiller Park, IL
EPRI-CM36	5/23/79	Custodis Construction Company	Dick Wilber	Chicago, IL
EPRI-CM37	5/31/79	United Engineers & Constructors	W. R. Thompson & R. E. Moore	Philadelpha, PA
EPRI-CM38	6/19/79	Pullman Kellogg	A. G. Sliger & R. H. Roberts	Houston, TX
EPRI-CM39	6/20/79	Utah Power & Light-Huntington 1	Fred Busch & Charles Kirby[d]	Huntington, UT

Table 1-1 (Continued)

Trip Number	Date of Visit	Site Visited	Persons Interviewed	Location
EPRI-CM40	6/21/79	Arizona Electric Power Coop.-Apache 2 & 3	Bob Maurice	Cochise, AZ
EPRI-CM41	6/22/79	Arizona Public Service-Cholla 1	Cleo Walker & Mike Machusak[e]	Joseph City, AZ
EPRI-CM42	6/22/79	Arizona Service-Cholla 2	Cleo Walker & Mike Machusak[e]	Joseph City, AZ
EPRI-CM43	6/26/79	South Carolina Public Service Authority-Winyah 2	Al Saunders	Georgetown, SC
EPRI-CM44	6/27/79	Alabama Electric Coop.-Tombigbee 2 & 3	Royce Hutcheson	Leroy, AL
EPRI-CM45	6/28/79	South Mississippi Electric Power Association-R.D. Morrow 1 & 2	Wayne Downs	Purvis, MS
EPRI-CM46	7/12/79	Burns & McDonnell	Clark Collier	Kansas City, MO

[a]Trip reports are included in the appendix to this report.

[b]Office visit.

[c]Telephone contact.

[d]Employed by Chemico.

[e]Employed by Research-Cottrell.

erosion by the solid particles. The problem of corrosion and erosion is a major concern in wet FGD systems.

Over 90 percent of the FGD systems being installed by utilities are of the lime or limestone slurry type. During the SO_2 absorption, the pH of the scrubbing liquor is lowered to less than 7. The scrubbing liquors also contain chloride ions introduced from the coal, the water, and the lime or limestone used in making up the scrubbing slurries. Since water pollution regulations usually preclude dumping the scrubbing liquor to surface or ground waters, closed loop recirculation of the liquid results in considerable buildup of soluble chlorides and other contaminants. The resultant acid chloride solutions can be quite corrosive. The power industry generally expects 20 years or more of service from equipment, and concern has been expressed about the corrosion failures that have occurred.

Judicious selection of materials of construction is one way to minimize some of the problems discussed above. Materials choices include alloys, lined carbon steel, plastics, and ceramics. One of the main questions when designing FGD systems is whether to use stainless steel or lined carbon steel in many of the critical areas. Stainless steels are corrosion resistant, resistant to scale adhesion, and easy to clean. Low-carbon (L-grade) stainless steel is especially popular since field-fabrication minimizes carbide precipitation in the heat-affected welding areas, a cause of intergranular corrosion. However, both Type 316 and Type 316L stainless steel are subject to corrosion, particularly at low pH and high chloride concentrations. Experience has shown that more highly alloyed construction materials may be needed in certain highly corrosive areas.

One way to provide corrosion-resistant scrubber materials at less cost than alloys is to use protective linings over carbon steel. Organic linings can theoretically withstand the low pH, high chloride condition much better than the Type 316 stainless steels. However, they are particularly vulnerable to temperature excursions. The other pitfall with linings is the quality of application.

When corrosion engineers decide to protect stacks, SO_2 absorbers, and ductwork from corrosion with inorganic linings instead of organic linings, they traditionally choose chemical-resistant masonry sheathings. However, since no masonry sheathing is completely impervious to all possible corrosive elements, an impervious membrane is usually inserted between the sheathing and the substrate. Jointing and bedding of the masonry units is accomplished with mortars based on a chemical-resistant resin or plastic. Jointing and bedding resins come from both the organic and inorganic classes of chemicals. Among the most popular organics are furans, epoxies, polyesters, vinyl esters, and phenolics. Inorganics include silicates and sulfur, and are required for high temperature applications.

Design is perhaps second in importance to materials selection as a tool for preventing corrosion in FGD systems. A little forethought can minimize the need for followup corrosion prevention measures such as the use of linings. Careless structural planning can frustrate all attempts to control corrosion by remedial measures. Crevices stand out as the single greatest cause of equipment failure due to corrosion. To help avoid crevices during design, it is important to specify butt welds wherever possible. Three ways to assure crevice free welds are (1) tungsten inert gas (TIG) welding with gas backup, (2) nonmetallic removable backup rings, and (3) consumable inert rings. The welding process itself is also critical. In addition, drainage should be accounted for by eliminating blind corners and recesses where solids and liquids can accumulate. Velocity effects should be anticipated by specifying reinforcing pads at the points where a high velocity fluid stream contacts a vessel wall. Temperatures should also be anticipated during design by avoiding both hot spots and cold spots.

In all cases, it is important to determine what equipment and design are adequate for the job. This judgment should include considerations of cost and anticipated service life.

Section 2

GENERAL DISCUSSION OF MATERIALS

A variety of construction materials have been used in the full-scale lime/limestone FGD facilities that have been built to date. These materials can be classified as follows:

- Metals
- Organic linings and plastics
- Ceramic and inorganic materials.

METALS

Metals have been used in most components of FGD systems. The compositions of the alloys that have been used are presented in Table 2-1. Unlined carbon steel can be utilized where alkaline (pH>7) conditions are maintained, such as in lime/limestone storage silos or in the piping that carries makeup slurry to the absorber section of the system. Where unlined metal is exposed to sulfurous and sulfuric acids, either condensed from the gas stream or as part of an acidic slurry, corrosion-resistant alloys are required. The corrosion problems are accentuated when the chloride concentration in the FGD system becomes significant.

The selection of alloys for FGD system components has been based on field tests in pilot plant or prototype units by several organizations (1,2). The alloys have undergone different types of attack in the various components of the FGD system. Pitting, crevice corrosion, stress-corrosion cracking, or erosion can occur in the system, depending on the conditions that exist in a given component. Pitting and crevice corrosion have been initiated under deposits and scale or where structural imperfections may exist. These conditions occur most often in the spray and quench sections of the prescrubber, as well as in the absorber. Stress-corrosion cracking has occurred in reheater tubes where chloride concentrations and temperatures are high. Generalized metal wastage has resulted from acid attack on surfaces which are at temperatures below the dew point of the gas stream. These surfaces are at the exit end of the system, primarily in the

Table 2-1

NOMINAL COMPOSITION OF ALLOYS USED IN FGD SYSTEM COMPONENTS
(Weight Percent)[a]

Alloy	Cr	Mo	Ni	Fe	Cu	C	Other
Wrought							
Inconel 625[b]	22	9	Balance	3	--	0.05	3.6 Cb + Ta
Hastelloy B[c]	1*	28	Balance	5	--	0.05*	2.5Co*
Hastelloy C-4[c]	16	16		3*	--	0.015*	2.0Co*, 0.7Ti*
Hastelloy C-276[c]	16	16	Balance	5	--	0.02*	2.5Co*, 4W
Hastelloy G[c]	22	6.5	Balance	20	2	0.05	2.5Co*, 1W* 2.1 Cb + Ta
Incoloy 825[b]	22	3	Balance	30	2	0.03	
Allegheny Ludlum AL-6X[d]	20	6	24	Balance	--	0.03	
Jessop JS-700[e]	21	4.5	25	Balance	--	0.05	0.3Cb
Jessop JS-777[e]	21	4.5	25	Balance	2.4	0.05	
Carpenter 20 Cb-3[f]	20	2.5	35	Balance	3.5	0.07*	
Haynes 20 Mod[c]	22	5	26	Balance	--	0.05*	
Type 304	19	--	9	Balance	--	0.08*	
Type 216	20	2.5	7	Balance	--	0.08*	0.3N, 8.5Mn
Type 316	17	2.5	12	Balance	--	0.08*	
Type 316L	17	2.5	12	Balance	--	0.03*	
Type 317	19	3.5	13	Balance	--	0.08*	
Type 317L	19	3.5	13	Balance	--	0.03*	
Type 317LM[g]	19	4.25	14	Balance	--	0.03*	
Type 317L Plus[e]	19	4.25	14	Balance	--	0.03*	
UHB904L[h]	20	4.5	25	Balance	1.5	0.02	1.75Mn
Type 409	12	--	--	Balance	--	0.05*	0.4Ti
Type 410	12	--	--	Balance	--	0.15*	
Type 430	17	--	--	Balance	--	0.12*	
E-Brite 26-1[d]	26	1	--	Balance	--	0.005*	
Titanium	--	--	--	--	--	0.10*	Balance Ti
Carbon steel	--	--	--	Balance	--	0.20*	
Cor-Ten[i]	0.5	--	--	Balance	0.3	0.07	1.2Mn, 0.3Si
Cast							
CF-3M	19	2	11	Balance	--	0.02*	
CF-8M	19	2	9	Balance	--	0.08*	
CG-8M	19	3	11	Balance	--	0.08*	
CD-4MCu	26	2	5	Balance	3	0.04*	
CN-7M	20	2	29	Balance	3	0.07*	
In-862	21	5	24	Balance	--	0.07*	
CW-12M-2	18	18	Balance	6	--	0.07*	
Ni-Hard, Type 1	1.4-4.0	--	3.3-5.0	Balance	--	3.0-3.6	1.3Mn, 0.8Si, 0.3P, 0.15S (all max.)
Ni-Hard, Type 4	7.0-11.0	--	5.0-7.0	Balance	--	2.5-3.6	1.3Mn, 1.0-2.2Si, 0.10P, 0.15S (all max.)

[a]Asterisks indicate maximum.

[b]Trademark of the International Nickel Co.

[c]Trademark of Stellite Div. of Cabot Corp.

[d]Trademark of Allegheny Ludlum Steel Corp.

[e]Trademark of Jessop Steel Corp.

[f]Trademark of Carpenter Technology Corp.

[g]Trademark of Eastern Stainless Steel Corp.

[h]Trademark of Uddeholm Corp.

[i]Trademark of U.S. Steel Corp.

ducting beyond the reheat section and in the stack. Sections of the FGD system in which the gas stream or the scrubber slurry moves at high velocity are subject to erosive attack.

Type 316 stainless steel has been attacked under some of the service conditions in an FGD system. Specimens of Type 316 stainless steel that were sensitized by heating prior to exposure suffered significant intergranular corrosion in 60 percent of FGD system exposure locations (3,4). This result emphasized the importance of using the low carbon grade (Type 316L) when weld fabrication was employed. Tests with Type 316L stainless steel showed that the general surface corrosion of this alloy in FGD system applications was low. However, localized attack in the form of pitting or crevice corrosion occurred frequently. An attempt was made to correlate this localized attack with the chloride content and the pH of the scrubbing liquor. In the pH range of 5 to 6 where most lime or limestone scrubber slurries operate, only a few hundred ppm of chlorides can be tolerated.

The beneficial effects of molybdenum in the alloys were noted, but when the various corrosion data were plotted, the rate of attack did not correlate well with molybdenum content (5). However, when the sum of the molybdenum and chromium content of the alloys was plotted against corrosion rate, a relationship was apparent. The rate of attack is inversely proportional to the sum of the molybdenum and chromium content. Therefore, alloys such as Hastelloy C-276 and Inconel 625, which are more expensive than Type 316L stainless steel, are required for the optimum corrosion resistance in FGD systems with acidic conditions and high chloride concentrations.

A large amount of Type 316L stainless steel has been used in FGD system components such as prescrubbers, absorbers, spray nozzles, reheaters, and dampers. Moderate use has been made of Inconel 625 in critical locations such as outlet ducts, outlet dampers, and reheaters. Hastelloy G, which has a lower molybdenum content than Inconel 625 or Hastelloy C-276, also has been utilized for vulnerable components. Carbon steel and high-strength, low-alloy steels such as Cor-Ten have been reserved for areas where alkaline conditions prevail, or are protected by a lining.

ORGANIC LININGS

Organic linings have been used extensively in various components of flue gas desulfurization systems including prescrubbers, absorbers, outlet ducts, stacks, and tanks. A summary list of these linings is shown in Table 2-2. They are attractive because their use to protect carbon steel provides the lowest price materials choice for many of these components. While rubber is one of the forms of organic lining it is generally placed in a separate category because it is applied in sheets rather than in liquid form. Two types of sheet rubber have been used for lining absorbers: natural (gum) and neoprene. Natural rubber is better than neoprene in both abrasion and chemical resistance, but neoprene is less flammable.

Rubber linings are subject to failure by debonding. Debonding is caused by liquids penetrating behind the sheets of rubber into the adhesive. This kind of failure can be promoted by lapping the sheets of rubber the wrong way so that the liquid flow is into the lap instead of over the lap. Since the scrubbing liquor is normally flowing down the absorber walls, the upper layer of rubber should overlap the lower layer. Some rubber-lined absorber vessels have caught fire. However, this is not a failure of the material but an accidental failure which may be caused by carelessness in welding or some other external source of ignition of the rubber.

Organic linings provide protection by acting as a physical barrier to exclude the corrosive environment from the underlying metal. To provide the necessary barrier properties, the lining must bond well to the metal surface and must not be displaced by the fluids to which it is exposed. Moreover, the lining must not be attacked by the chemicals in the environment nor be degraded by the temperatures to which it is exposed. This limits the choice of resins that can be used. Polyester, vinyl ester, epoxy, and fluoropolymer resins have been used in linings for various components of FGD systems. The maximum recommended service temperatures for resin based linings are 180°F (82°C) (wet) and 250°F (121°C) (dry) for polyester and epoxy, 360°F (182°C) (dry) for vinyl ester, and 400°F (204°C) for fluoropolymer. Because of its high cost, the latter resin has been used only in linings for components that are exposed to relatively high temperatures, e.g., outlet ducts downstream from the bypass junction and stacks.

In order to provide an effective barrier, the organic linings used in FGD systems are applied much more thickly than typical coatings. Moreover, the polyester and vinyl ester linings generally contain a flake-type filler which decreases the permeability of the film and provides reinforcement. Glass flakes are commonly used with polyester and, in this case, the lining is trowel-applied in two coats to a nominal thickness of 80 mils (2 mm) over a 2 to 3 mil (0.05 to 0.08 mm)

Table 2-2

SUMMARY OF ORGANIC LININGS UTILIZED IN FGD SYSTEMS

Lining Type	Trade Names	Method of Application	Total Thickness
Natural (gum) rubber	--	Applied in sheets which are bonded to steel with adhesive	3/16 inch (4.8 mm)
Neoprene	LS-576	Applied in sheets which are bonded to steel with adhesive	1/4 inch (6.4 mm)
Glass flake-filled polyester	Flakeline 103 Resista-Flake 1103 Protecto-Flake 500 and 550[a] Rigiflake 4850 and 4855[b]	Trowel applied in two coats	80 mils (2.0 mm)
Mica flake-filled polyester	Flakeline 151[c] Flakeline 252 Resista-Flake 1251 Rigiflake 489	Spray applied in two coats	40 mils (1.0 mm)
Variation in flake-filled polyester	Resista-Flake 1151	First coat (glass flake) trowel applied and top coat (mica flake) spray applied	60 mils (1.5 mm)
Inert flake-filled vinyl ester	Plasite 4004, 4005, 4020, and 4030	Spray applied in two coats	40 mils (1.0 mm)
Glass cloth or mat-reinforced	Coroline 505 and 505AR[d] (epoxy) Ceilcrete 2500AR (polyester) Rigiflake 413GS (epoxy) Plasite 7122 (epoxy phenolic)	Trowel applied except for mat saturant	1/8 inch (3.2 mm)
Fluoroelastomer	CXL-2000 Flakeline 282-X[e]	Spray applied in six or seven coats	40 mils (1.0 mm)
Miscellaneous types		Spray applied	
Bitumastic	--		
Epoxy	Flakeline E[e]		
Coal tar epoxy	Carbomastic 14		
Non-asphaltic mastic	Stackfas		

[a]Protecto-Flake 550 has a chlorinated polyester resin binder.

[b]Fire retardant version of 4850.

[c]No longer supplied.

[d]AR designates abrasion resistant

[e]Experimental lining.

spray-applied primer. Mica flakes have been used instead of glass flakes in some cases in order to lower the materials cost somewhat and permit spray application which further lowers the applied cost. These linings are applied in two coats to a nominal thickness of 40 mils (1 mm). However, mica flake-filled polyester linings are not as durable as glass flake-filled polyester linings. A lining variation that represents a compromise is the use of a 20 mil (0.5 mm) spray-applied mica flake-filled coat over a 40 mil (1 mm) trowel-applied glass flake-filled coat. Inert flake-filled vinyl ester linings are spray-applied in two coats to a nominal thickness of 40 mils (1 mm) over a thin, spray-applied primer. Fluoroelastomer linings are also spray-applied to a nominal thickness of 40 mils (1 mm), but this is done in 6 or 7 coats.

In components such as venturi prescrubbers where high abrasion resistance is required, epoxy or polyester linings reinforced with glass cloth or inert matting have been used. These linings are trowel-applied to a nominal thickness of 1/8-inch (3 mm) and may contain special abrasion-resistant fillers such as alumina to improve wear resistance. Some miscellaneous types of linings have also been used in FGD system components. For example, bitumastic, epoxy, and coal tar epoxy linings have been used to a limited extent in tanks and thickeners.

In order to perform their intended function as a protective barrier, the organic linings must be properly applied to a carefully cleaned metal surface, and then properly cured. Blasting to white metal provides the best bonding surface. However, surface preparation under the conditions that often exist inside scrubber components is very difficult. The freshly blasted surface can rust rapidly, especially if the humidity is high. Therefore, the surface should be quickly coated with a thin film of primer to protect it and provide good bond for the thicker layers of lining to follow. The primer enhances adhesion because its low viscosity enables it to wet the metal and to flow into the surface irregularities. Application of the lining must be carefully monitored by spark testing (or other suitable method) to make sure it does not contain voids or pinholes. Moreover, time of application between coatings can be highly important with most materials to obtain good intercoat adhesion.

Failure of organic linings can occur by blistering, debonding, wear from abrasive slurries, and temperature excursions. The combination of high temperature and strong acid condensate, which can exist in stacks, is very destructive to almost all types of organic linings. It is not uncommon to make spot repairs in linings where failures have been localized. This can present a difficult problem.

Surface preparation requires removal of the old lining and all corrosion product from the metal to expose a bare metal surface. High humidity inside components that have been operating adds to the problem. Complete replacement of a lining is obviously more difficult than the original application because the old lining must be removed, and environmental conditions within a component that has operated are generally much worse than in a new unit.

CERAMIC AND INORGANIC MATERIALS

Inorganic materials are used in prescrubbers, spray nozzles, slurry pumps, outlet ducts, bypass ducts, and stacks of FGD systems. Table 2-3 is an overview of the types of inorganic materials utilized. The materials include prefired bricks and shapes, hydraulic bonded concretes and mortars, and chemically bonded concretes and mortars, all of which are used as linings where temperature resistance, chemical resistance, and/or abrasion resistance are required. Prefired shapes are also used for spray nozzles and pump components.

Acid-resistant bricks (ARB) are commonly used construction materials for stack linings. They are made of fireclay and fired to give either low (ASTM C279 type L) or high (type H) water absorption, with limits of 1.0 and 6.0 percent, respectively. Type H bricks are more commonly used in stacks because they are more resistant to thermal shock than the denser type L bricks. Chemically the two types are similar, with 60 to 70 percent SiO_2, 15 to 30 percent Al_2O_3, and less than 10 percent other oxides. There are actually two types of type L brick, a red shale variety not commonly used in stacks, and the fireclay (buff colored) type which is sometimes used.

Alumina (Al_2O_3) bricks are more abrasion resistant than acid-resistant bricks and will also withstand hot sulfuric acid conditions so that they have been used to line venturi throats. They are made from prefired Al_2O_3 aggregates by refiring pressed shapes. The Al_2O_3 spray nozzles are chemically similar (probably over 90 percent Al_2O_3) to the bricks but are fabricated from fine powders only (no aggregates) and are generally denser and have a finer texture than bricks.

Silicon carbide (SiC) shapes have high abrasion and chemical resistance and are used for spray nozzles and pump components, as well as for lining venturi throats. Silicon carbide (SiC) shapes may be bonded in one of four ways: (1) with clay, (2) with silicon oxynitride, (3) with silicon nitride, or (4) with

Table 2-3

OVERVIEW OF INORGANIC MATERIALS UTILIZED IN FGD SYSTEMS

	Type of Material				
		Hydraulic Bonded		Chemically Bonded	
Type of Use	Prefired Bricks and Shapes	Concretes	Mortars	Concretes	Mortars
Linings					
Prescrubbers and absorbers	Al_2O_3, ARB[a], SiC, Refrax[b]	Kaocrete HS Pre-Krete G-8	Portland cement	--	Sauereisen No. 33
Outlet ducts	--	Kaocrete HS Pre-Krete G-8 Plibrico gunite	--	Sauereisen No. 54	--
Bypass ducts	Pennguard block	Pre-Krete G-8	--	--	--
Stacks	LARBa, HARBa	Pre-Krete G-8 Haydite/Lumnite	Portland cement	--	Sauereisen No. 33 Sauereisen No. 65 Corlok B Pennwalt HES
Spray nozzles	Al_2O_3, SiC, Refrax[b]	--	--	--	--
Pump components	SiC	--	--	--	--

[a]ARB = acid-resistant brick, Type L or Type H.

[b]Si_3N_4 bonded SiC.

additional SiC (self-bonded). Clay-bonded SiC is manufactured by firing in air and is the least expensive type of process, yet would probably be suitable for producing low temperature FGD components. Silicon oxynitride bonds are formed by firing clay or siliceous-bonded SiC articles in a nitrogen environment. The SiC (or carbon additives) create a reducing environment in which the oxides are first reduced, then nitrided. The advantages of this type of bond system are the lower cost of the raw materials compared to pure nitride or SiC bond processes, and the use of relatively simple muffle furnaces. Nitride-bonded SiC is produced by firing a blend of SiC aggregate and fine silicon powder in a nitrogen environment. To avoid oxidation of the silicon powder, the furnace is preferably evacuated and purged with nitrogen several times before heating to the 2600°F (1430°C) nitriding temperature. This process is slow because it is exothermic and must be carefully controlled, and therefore the products are relatively expensive. Refrax® is a trade name for materials produced by this technique. Self-bonded SiC is produced by reacting silicon and carbon in an inert environment at temperatures above those used for producing silicon nitride. It is a relatively expensive material used for high temperature applications and would probably not be used in FGD components.

Prefired bricks and shapes will resist service conditions that occur in FGD systems except perhaps for hydrofluoric acid (HF) which could attack silicate bonds. However, mortar failures can cause collapse of a lining constructed of prefired materials. Design aspects which could cause failure include mechanical stresses from shrinkage, insufficient thermal expansion allowances, mechanical attachment system, vibration, and/or thermal or mechanical shock. Ceramic spray nozzles are susceptible to brittle fracture during installation, cleaning, or pressure surges.

Hydraulic-setting, cement-bonded concretes (hydraulic concretes) are commonly used as prescrubber, outlet duct, and stack lining materials in FGD systems. Kaocrete HS, Pre-Krete G-8, and Haydite/Lumnite are believed to contain calcium aluminate cement which sets faster and is somewhat more acid-resistant than portland cement. Also, calcium aluminate cement can withstand temperatures of 500°F (260°C) without the strength degradation common to portland cement. The aluminum hydroxide phase which forms as one of the hydrate reaction products in calcium aluminate cements is less readily dissolved by dilute acid solutions than the calcium hydroxide which forms in portland cement. However, in strong sulfuric acid solutions (pH below 4) the calcium aluminate cements are attacked by a solution mechanism. Because they do not release $Ca(OH)_2$ as a hydration product, calcium aluminate cements are significantly more resistant to deterioration caused by the in-situ formation of calcium sulfate hydrates such as ettringite ($3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 32H_2O$) or monosulfate ($3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 11H_2O$). These compounds are believed to be responsible for cracking of portland cement bonded materials exposed to sulfate-rich solutions (not necessarily sulfuric acid) because of the large volume change accompanying their formation. Because calcium aluminate cements are resistant to hydration reactions which cause cracking, and to solution by dilute acids, they are commonly used in mortars for constructing stack linings, and in refractory castable mixes used as erosion resistant linings in venturi prescrubbers and quench ducts. However, if condensation occurs, and the pH of the attacking solution becomes low enough, failures by bond solution might be expected, resulting in the loosening of the aggregate and erosive wear of the lining.

Chemically bonded mortars are commonly used to bond ARB stack linings. Chemically bonded concrete mixes (commonly applied by gunite technique although they can also be cast or troweled) can be used as linings. They generally contain siliceous aggregates, a sodium silicate, potassium silicate, or colloidal silica bond phase, and a silicofluoride, phosphate, or organic bond gelling agent (like chemically bonded mortars). However, they are formulated to set much faster than mortars, and may have additives which may help them stick to vertical walls without slumping.

The reaction products of these cements are high silica phases which are not easily dissolved by acidic solutions. However, sodium silicate undergoes a sulfidation reaction with sulfuric acid to form a silica and Na_2SO_4, the latter of which hydrates to $Na_2SO_4 \cdot 10H_2O$ which can crack the cement. A similar reaction occurs with potassium silicate, but an amorphous reaction product is formed which does not produce a detrimental expansion force. To avoid these problems, commercial materials either modify sodium silicate bonds to make them resistant to hydration, or utilize potassium silicate or colloidal silica bonds. Since chemically bonded concretes can withstand hot acidic environments, they offer an abrasion-resistant alternative to organic linings. However, they have a finite permeability (and may crack), so any condensed acid may ultimately reach the substrate to which they are applied.

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Section 3

MATERIALS PERFORMANCE

DESCRIPTION OF FGD SYSTEMS VISITED

The FGD installations listed in Table 3-1 were visited. The visits included 26 facilities and 39 separate FGD systems with representation by limestone and lime scrubbing and by eastern and western coal. Table 3-1 includes background information on each FGD system to help define the conditions under which the materials of construction must perform. For example, the method of particulate removal is an indicator for the amount of fly ash to be expected in the scrubber slurry. Bypass capability and type of stack gas reheat determine the conditions in the outlet duct and the stack. The method of waste disposal (open vs. closed-loop) can be an indicator for the amount of chloride buildup in the scrubbing liquor, although other factors such as the chloride content of the coal and the makeup water are involved. The start-up date for the FGD system is an indicator for the service life of the system components. Information on materials was collected for each of the following FGD equipment categories:

- Prescrubbers
- Absorbers
- Spray Nozzles
- Mist Eliminators
- Reheaters
- Fans
- Ducts
- Expansion Joints
- Dampers
- Stacks
- Storage Silos
- Ball Mills and Slakers
- Pumps

Table 3-1

DESCRIPTION OF FGD SYSTEMS VISITED

Utility and Plant	Size (MW)	Sulfur in Coal (Wt %)	FGD Supplier	Reactant for SO_2 Removal	Method of Particulate Removal	Type of Prescrubber	Type of SO_2 Absorber	Number of Absorber Modules	Bypass Capability	Type of Stack Gas Reheat	Method of Sludge Dewatering	Method of Waste Disposal	Start-Up Date
Alabama Elec. Coop.													
Tombigbee 2	255	1.5-1.8	Peabody	Limestone	ESP	Quench duct	Spray tower	2	Yes	Bypass	None	Pond; open loop	9/78
Tombigbee 3	255	1.5-1.8	Peabody	Limestone	ESP	Quench duct	Spray tower	2	Yes	Bypass	None	Pond; open loop	6/79
Arizona Elec. Power Coop.													
Apache 2	195	0.4-0.5	R-C	Limestone	Hot ESP	None	Packed tower	2	Yes	Bypass	None	Pond; open loop	2/79
Apache 3	195	0.4-0.5	R-C	Limestone	Hot ESP	None	Packed tower	2	Yes	Bypass	None	Pond; open loop	6/79
Ariz. Public Serv.													
Cholla 1	115	0.4-0.6	R-C	Limestone	Multiclone and FDS	Flooded disc venturi	Packed tower	2	Yes	In-line steam coils	None	Pond; open loop	12/73
Cholla 2	285	0.4-0.6	R-C	Limestone	Multiclone and FDS	Flooded disc venturi	Packed tower	2	Yes	In-line steam coils	None	Pond; open loop	5/78
Central Illinois Light													
Duck Creek	400	3.4	R/E	Limestone	ESP	None	Ventri-Sorber®	4	Yes	None	None	Pond; closed loop	7/76 & 7/78[a]
C & S Ohio Elec.													
Conesville 5	410	4.5	UOP	Thiosorbic lime	ESP	Quench duct	One-stage TCA	2	Yes	None	Vacuum filter	Landfill; closed loop	1 & 11/77
Conesville 6	410	4.5	UOP	Thiosorbic lime	ESP	Quench duct	One-stage TCA	2	Yes	None	Vacuum filter	Landfill; closed loop	4/78
Commonwealth Edison													
Will County 1	167	0.5-4.0	B&W	Limestone	Venturi	Venturi	Tray tower	2	Yes	In-line steam coils	Vacuum filter	Landfill; closed loop	2/72
Duquesne Light													
Elrama	494	2.0	Chemico	Thiosorbic lime	ESP and venturi	None	Venturi	5	No	None[b]	Vacuum filter	Landfill; open loop	10/75
Phillips	387	2.3	Chemico	Thiosorbic lime	ESP and venturi	None	Venturi	4	No[c]	None[b]	Vacuum filter	Landfill; open loop	7/73
Indianapolis P & L													
Petersburg 3	515	3.0-4.5	UOP	Limestone	ESP	Quench duct	Three-stage TCA	4	Yes	Indirect hot air	Vacuum filter	Landfill; closed loop	12/77
Kansas City P & L													
Hawthorn 3	100	4.0	CE	Lime[d]	One-stage marble bed	None	One-stage marble bed	2	Yes	In-line hot water tubes	Thickener	Pond; open loop	11/72
Hawthorn 4	100	4.0	CE	Lime[d]	One-stage marble bed	None	One-stage marble bed	2	Yes	In-line hot water tubes	Thickener	Pond; open loop	8/72
La Cygne 1	870	5.4	B&W	Limestone	Venturi	Venturi	Two-stage tray tower	8	No	In-line steam coils	None	Pond; open loop	6/73
Kansas Power & Light													
Lawrence 4 (old)	125	3.3-4.0	CE	Limestone[e]	One-stage marble bed	None	One-stage marble bed	2	Yes	In-line hot water tubes	None	Pond; closed loop	10/68
Lawrence 4 (new)	125	0.9	CE	Limestone	Rod venturi	Rod venturi	Spray tower	2	Yes	In-line hot water tubes	Thickener	Pond; closed loop	1/77
Lawrence 5 (old)	400	3.3-4.0	CE	Limestone[e]	One-stage marble bed	None	One-stage marble bed	8	Yes	In-line hot water tubes	None	Pond; closed loop	9/71
Lawrence 5 (new)	400	0.9	CE	Limestone	Rod venturi	Rod venturi	Spray tower	2	Yes	In-line hot water tubes	None	Pond; closed loop	4/78
Kentucky Utilities													
Green River	52	3.5-4.0[f]	AAF	Lime	Venturi	Venturi	Mobile bed	1	Yes	None	None	Pond; closed loop	9/75

Table 3-1 (Continued)

Utility and Plant	Size (MW)	Sulfur in Coal (Wt %)	FGD Supplier	Reactant for SO_2 Removal	Method of Particulate Removal	Type of Prescrubber	Type of SO_2 Absorber	Number of Absorber Modules	Bypass Capability	Type of Stack Gas Reheat	Method of Sludge Dewatering	Method of Waste Disposal	Start-Up Date
Louisville G & E													
Cane Run 4	178	3.9	AAF	Carbide lime	ESP	Quencher	Mobile bed	2	Yes	Fuel-oil fired	Thickener	Pond; open loop	8/76
Cane Run 5	190	3.8	CE	Carbide lime	ESP	None	Spray tower	2	Yes	In-line steam coils	Thickener	Pond; open loop	12/77
Mill Creek 3	425	3.9	AAF	Carbide lime	ESP	Quencher	Mobile bed	4	Yes	In-line steam coils[f]	Thickener	Pond; open loop	7/78
Paddy's Run 6	65	3.7	CE	Carbide lime	ESP	None	Two-stage marble bed	2	Yes	Natural gas burners	Vacuum filter	Landfill; closed loop	4/73
Minnkota Power Coop.													
Milton R. Young 2	460	0.7	CEA	Alkaline fly ash	ESP	None	Spray tower	2	Yes	Bypass	Vacuum filter	Landfill; closed loop	5/77
Montana Power													
Colstrip 1	360	0.7	CEA	Lime/alkaline fly ash	Venturi	None	Venturi and spray zone	3	No	In-line steam coils	None	Pond; closed loop	11/75
Colstrip 2	360	0.7	CEA	Lime/alkaline fly ash	Venturi	None	Venturi and spray zone	3	No	In-line steam coils	None	Pond; closed loop	8/76
Northern States Power													
Sherburne 1	720	0.8	CE	Limestone/ alkaline fly ash	Rod venturi	Rod venturi	One-stage marble bed	12	No	In-line hot water tubes	Thickener	Pond; open loop	5/76
Sherburne 2	720	0.8	CE	Limestone/ alkaline fly ash	Rod venturi	Rod venturi	One-stage marble bed	12	No	In-line hot water tubes	Thickener	Pond; open loop	4/77
Pennsylvania Power													
Bruce Mansfield 1	825	2.0-5.0	Chemico lime	Thiosorbic	Venturi	Venturi	Venturi	6	No	None[b]	Thickener	Pond; open loop	4/76
Bruce Mansfield 2	825	2.0-5.0	Chemico lime	Thiosorbic	Venturi	Venturi	Venturi	6	No	None[b]	Thickener	Pond; open loop	10/77
S. Carolina Public Service													
Winyah 2	2809	1.0	B&W	Limestone	ESP	Quencher	One-stage tray tower	1	Yes	Bypass[h]	Thickener	Pond; open loop	8/77
S. Miss. Elec. Power													
R. D. Morrow 1	200	1.6	R/E	Limestone	ESP	None	Ventri-Sorber®	1	Yes	Bypass	Vacuum filter	Landfill; closed loop	9/78
R. D. Morrow 2	200	1.6	R/E	Limestone	ESP	None	Ventri-Sorber®	1	Yes	Bypass	Vacuum filter	Landfill; closed loop	6/79
S. Illinois Power Coop.													
Marion 4	184	~3.5	B&W	Limestone	ESP	Quencher	Two-stage tray tower	2	Yes	None	Centrifuge	Landfill; closed loop	4/79
Springfield City Utilities													
Southwest 1	194	3.5-4.0	UOP	Limestone	ESP	Quench duct	Three-stage TCA	2	Yes	None	Vacuum filter	Landfill; closed loop	4/77
TVA													
Widows Creek 8	550	4.0	TVA	Limestone	Venturi	Venturi	Five-stage tray tower	4	Yes	Indirect hot air	None	Pond; closed loop	5/77
Utah Power & Light													
Huntington 1	432	0.6	Chemico	Lime	ESP	None	Spray tower	4	Yes	Bypass and indirect hot air	Vacuum filter	Landfill; closed loop	5/78

[a] One module started up in July, 1976, and operated intermittently until March, 1977; all four modules started up in July, 1978.

[b] Oil-fired reheaters were installed but never used because of operating problems.

[c] The FGD system can be bypassed, but shutdown of the boilers is necessary to divert the flow.

[d] Converted from limestone injection into boiler to tail-end lime scrubbing.

[e] Limestone injection into the boiler.

[f] Not yet installed.

[g] Only half of the flue gas is scrubbed.

[h] Blended in stack; scrubbed gas enters about 100 feet (30 m) above bypass breeching.

Piping and Valves

Tanks and Thickeners

Agitators and Rakes

Vacuum Filters and Centrifuges

Pond Linings.

PRESCRUBBERS

Prescrubbers are defined as vessels or chambers through which the hot flue gas passes and is wetted without significant SO_2 removal. They are located in the flue gas flow train immediately upstream of the SO_2 absorbers and may be attached directly to the absorber vessel or connected to the absorber vessel with a duct. Prescrubbers cool the flue gas from the air preheater exit temperature (about 300°F; 149°C) to the adiabatic saturation temperature (about 125°F; 52°C). There are basically two types of prescrubbers: (1) a quench or saturation duct with water sprays which cools hot gas already cleaned of particulates by an electrostatic precipitator, and (2) rod, constricted throat, plumb bob, or flooded disc (all usually variable throat) venturi systems which cool the gas and remove particulates.

Lime/limestone scrubbing liquor is usually used in the prescrubber so that it operates at a pH of about 4 to 6. In some cases, makeup water or reclaimed water is used in quench or saturation ducts which means that the operating pH is about 1 to 3. The low pH exit liquor from a quench or saturation duct is sent to the SO_2 absorber to be mixed with the lime/limestone scrubbing liquor. Most of the chloride in the flue gas is removed in the prescrubber but the chloride content of the exit liquor depends upon the chloride content of the coal and the water balance for the FGD system. The type of prescrubber and materials of construction for the prescrubber used at each installation visited for this study are summarized in Table 3-2. Additional details can be found in the appropriate trip reports included in the appendix.

Prescrubbers are constructed of lined carbon steel or unlined alloys. Organic lining materials used to date in prescrubbers appear to have failed by erosion when unprotected, but appear to be providing corrosion protection when covered with erosion-resistant ceramic materials. Inorganic concrete linings have held up quite well in some installations, but have also failed rapidly in others. Failure may be related to acidic environmental conditions in these cases. Alloys

Table 3-2

PRESCRUBBERS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Description of Component	Original Materials	Comments
Alabama Electric Coop. Tombigbee 2 & 3	9/78 & 6/79	Quench duct	Incoloy 825	
Arizona Electric Power Coop. Apache 2 & 3	2/79 & 6/79	No prescrubber	Not applicable	
Arizona Public Service Cholla 1	12/73	Flooded disc venturi; variable throat	CS[b] above venturi; 316L SS below and for intervals	Severe chloride corrosion; ARB/Corobond[c] mortar overlay added to sump and floor in 1975; disc and venturi throat replaced with 316L SS in 1/77
Cholla 2	5/78	Flooded disc venturi; variable throat	CS lined with Coroline 505AR[d] vessel; Hastelloy C disc and deflector plate; SiC bricks/Sauereisen No. 33 in throat; SiC bricks/Corobond mortar on walls and floor	
Central Illinois Light Duck Creek	7/76	No prescrubber	Not applicable	
Columbus & Southern Ohio Electric Conesville 5 & 6	1/77 & 4/78	Quench duct	Carpenter 20	
Commonwealth Edison Will County 1	2/72	Variable throat venturi	Venturi and sump are Cor-Ten lined with Plasite 7122 plus Kaocrete HS: throat is SiC blocks	SiC blocks removed in 1976 to eliminate clogging
Duquesne Light Elrama	10/75	No prescrubber	Not applicable	
Phillips	7/73	No prescrubber	Not applicable	
Indianapolis Power & Light Petersburg 3	12/77	Quench duct	CS lined with Pre-Krete G-8	Pre-Krete G-8 on internal struts and sidewalls is eroding
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	No prescrubber	Not applicable	
La Cygne 1	6/73	Variable throat venturi	Venturi and sump are 316L SS lined with Plasite 7122 plus Kaocrete HS; throat is SiC blocks	Kaocrete in sump needs patching
Kansas Power & Light Lawrence 4 & 5 (old)	10/68 & 9/71	No prescrubber	Not applicable	
Lawrence 4 & 5 (new)	1/77 & 4/78	Rod venturi	Venturi is 316L SS; rods are Noryl plastic over FRP	
Kentucky Utilities Green River	9/75	Variable throat venturi	Venturi is 316 SS above throat, CS lined with Pre-Krete G-8 below throat; sump is CS lined with ARB plus Pre-Krete G-8	Localized erosion of Pre-Krete in sump elbow and at venturi spray band repaired with same
Louisville Gas & Electric Cane Run 4	8/76	Quencher	Vessel is CS lined with Pre-Krete; deflector is 316 SS	
Cane Run 5	12/77	No prescrubber	Not applicable	
Mill Creek 3	7/78	Quencher	Vessel is CS lined with Pre-Krete	
Paddy's Run 6	4/73	No prescrubber	Not applicable	

Table 3-2 (CONTINUED)

Utility and Plant	Start-Up Date	Description of Component	Original Materials	Comments
Minnkota Power Coop. Milton R. Young 2	5/77	No prescrubber	Not applicable	
Montana Power Colstrip 1 & 2	11/75 & 8/76	No prescrubber	Not applicable	
Northern States Power Sherburne 1	5/76	Rod venturi; adjustable	316L SS throat and rods; sump walls are CS lined with Flakeline 151	Lining repaired in 9/76 and 316L SS wear plates added to sump walls; rod erosion repaired with 316L SS angle irons
Sherburne 2	4/77	Rod venturi; adjustable	Same as Unit 1 except Flakeline 151AR Lining	Lining debonded and replaced with Flakeline E in 1978
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	Variable throat venturi; plumb bob	Vessel is CS lined with Rigiflake 4850; SS inlet; ARB lining in throat	SS wear plates added to top of plumb bob
South Carolina Public Service Winyah 2	8/77	Venturi quencher	Vessel and sump are CS lined with Kaocrete; 316L SS wear band	
South Mississippi Elec. Power R. D. Morrow 1 & 2	9/78 & 6/79	No prescrubber	Not applicable	
Southern Illinois Power Coop. Marion 4	4/79	Quencher	Quench vessel is CS lined with Resista-Flake 1251 plus Kaocrete HS; sump is CS lined with Resista-Flake 1251	
Springfield City Utilities Southwest 1	4/77	Quench duct	CS lined with Pre-Krete G-8	Lining failed and replaced with Uddeholm 904L liner plates in 1977
Tennessee Valley Authority Widows Creek 8	5/77	Variable throat venturi	Venturi is 316L SS plus SiC castable in honeycomb; throat is Al_2O_3 brick; sump is rubber-lined Cor-Ten	Neoprene rubber debonded in sump; replaced with 316L SS plate in 1/78; some corrosion at welds
Utah Power & Light Huntington 1	5/78	No prescrubber	Not applicable	

[a]Any materials problems identified are indicated under comments.

[b]Abbreviations used are:
ARB = acid-resistant brick
CS = carbon steel
SS = stainless steel.

[c]Furan-resin-based mortar.

[d]Trade names of linings are identified by generic type in Table 2-2.

have performed quite well in prescrubbers except where chloride attack is a problem.

Quench and Saturation Duct Systems

Although particulates are normally removed from the hot gas before it enters a quench duct, the lime/limestone slurry usually sprayed into the duct to avoid acidic conditions can cause an erosion problem. Due to the hot erosive conditions, organic linings are not used in this area unless they are protected with another material. Marion is the only unit which uses an organic membrane (Resista-Flake 1251) and a protective concrete (Kaocrete HS) in a quench duct. All other units initially utilized either concrete-lined carbon steel (Pre-Krete G-8 at Petersburg, Cane Run 4, Mill Creek, and Southwest, and Kaocrete at Winyah) or Carpenter 20 alloy (Tombigbee and Conesville). The longest continuing operating experience thus far with hydraulic bonded concrete is more than 3-1/2 years at Cane Run 4 and with Carpenter 20 is more than 3 years at Conesville.

Materials problems were reported for only two units, Petersburg and Southwest, both of which use limestone reactant and high sulfur coal. Southwest has replaced the Pre-Krete G-8 lining with a Uddeholm 904L lining over the carbon steel. The Uddeholm alloy is in good condition after more than 2 years of service. Petersburg is experiencing erosion problems with the Pre-Krete after less than a year of operation. Although the failure mechanism at both units is unknown, Pre-Krete G-8 is known to be an hydraulic bonded concrete (calcium aluminate cement). This type of bond system is generally less resistant to very acidic conditions than chemically (gelled silicates) bonded concretes (generally applied by guniting) and mortars, and bond degradation may be occurring either by solution or sulfidation. The prescrubbers at Southwest and Petersburg would be especially susceptible to this failure mechanism because thickener overflow, rather than limestone slurry, is used as the feed liquor. The feed liquor to the prescrubbers at Cane Run 4 and Mill Creek is the same as the absorber feed liquor and therefore contains lime slurry to avoid acidic conditions.

Winyah has a venturi quencher which does not remove particulates. The quencher in this limestone FGD system is lined with Kaocrete which has given no problems with low sulfur coal. The feed liquor to the quencher contains limestone slurry.

Venturi Systems

The hot, wet, erosive environment of venturi prescrubbers requires the use of erosion-resistant materials. Organic linings covered with hydraulic bonded inorganic concretes are used in Will County and La Cygne (both use Kaocrete over Plasite 7122), both of which are B&W systems. It is possible that the Winyah venturi quencher lining (Kaocrete) is also backed with an organic lining, although the information obtained on this B&W system does not specifically indicate it. No major problems have been reported with these prescrubbers which have operated for more than 6-1/2 and 8 years thus far at La Cygne and Will County, respectively.

Organic linings covered with prefired ceramic bricks or blocks are used in the throat areas of venturis at Cholla 2, Will County, La Cygne, Bruce Mansfield, and Widows Creek. The blocks at Will County have been removed to eliminate plugging but no other problems were noted. Evidently, the Kaocrete lining at Will County provides sufficient erosion protection in the throat area. Although not used initially, SiC (silicon carbide) bricks have also been added to high wear areas of the Cholla 2 prescrubber. There is insufficient operating time to distinguish between the performance of Al_2O_3 and SiC bricks, both of which should provide long service.

Organic linings have been used without a protective cover in Cholla 2 (bricks added to some areas), for an unsuccessful repair at Cholla 1, at Sherburne (failures), at Bruce Mansfield (stainless steel wear plates added), and in the Widows Creek sump (rubber debonded). Except for Sherburne 2 (debonding) and Widows Creek, the organic lining failures appear to be caused by erosion rather than by debonding, as evidenced by the addition of wear plates after lining repairs at some units.

Inorganic concrete linings without organic linings underneath are used at Winyah (Kaocrete), Widows Creek (SiC castable), and Green River (Pre-Krete G-8). Only Green River, which has been in operation for more than 4 years, reported the need for localized repair of eroded areas.

Unlined alloys are used in venturis at new Lawrence 4 and 5 (Type 316L stainless steel), Cholla 1 (chloride attack of Type 316L stainless steel), Cholla 2 (Hastelloy C), Sherburne (Type 316L stainless steel throat), Green River (Type 316L stainless steel above throat), and Winyah (Type 316L stainless steel wear band). The length of service thus far ranges from 1-1/2 to 6 years at Cholla 2 and Cholla 1, respectively. At Lawrence, the old marble bed flue gas cleaning systems have been replaced with new venturi-spray tower units. The 2,000 ppm chloride content in the Cholla 1 system has caused rapid attack by pitting and stress corrosion of the Type 316L stainless steel vessel, and resulted in a switch to mat-reinforced epoxy (Coroline 505AR) lined carbon steel (vessel) and Hastelloy C (internals) for Cholla 2. The only erosion problem identified is of the Type 316L stainless steel rods at Sherburne 1. These rods are subjected to the full fly ash loading of the flue gas at high velocity. However, because of their relative erosion resistance, unlined Type 316L stainless steel wear plates have been added to areas at Sherburne 1, Bruce Mansfield, and Widows Creek. The chloride attack problem of Type 316L stainless steel at low pH levels is leading to the selection of more chloride resistant alloys such as Type 317L stainless steel, Uddeholm 904L, Incoloy 825, and others for prescrubbers in FGD systems now in the design and construction stage.

ABSORBERS

Absorbers are vessels in which the flue gas is contacted with a lime or limestone slurry for SO_2 removal by chemical reaction. They are located in the flue gas train downstream from the prescrubber or electrostatic precipitator. The flue gas enters the absorber from an inlet duct (or directly from a prescrubber) at either about 125°F (52°C) or about 300°F (149°C) depending upon whether or not there is a prescrubber. The flue gas exits the absorber to an outlet duct at the adiabatic saturation temperature of the gas (about 125°F; 52°C). The conditions in the absorber are similar to those in prescrubbers where lime/limestone scrubbing liquor is used, i.e., pH of 4.5 to 6.5. The chloride content of the scrubbing liquor depends upon how the prescrubber and absorber loops are tied together. The chloride content will be lower if liquor from the prescrubber is prevented from entering the absorber loop. In most cases, there is little or no fly ash in the absorber loop because of prior particulate removal in an electrostatic precipitator or prescrubber. However, there are a few cases where the SO_2 absorber is also used as the primary fly ash removal device (venturis at Elrama, Phillips, and Colstrip, and marble beds at Hawthorn and old Lawrence 4 and 5). Also, some FGD systems with wet particulate removal have a common scrubbing loop for the prescrubber and the absorber (Will County, La Cygne, Green River, and Sherburne) and one system utilizes an alkaline fly ash slurry as the SO_2 removal reagent in the absorber even though the ash is first removed upstream in an electrostatic precipitator (Milton R. Young).

Absorbers used for desulfurization of flue gas incorporate a variety of designs and many different materials of construction. A brief matrix of designs and materials is given in Table 3-3. More detailed information is given in the trip reports which are appended to this report. Almost every absorber incorporates a

Table 3-3

ABSORBERS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Description of Component	Original Materials	Comments
Alabama Electric Coop. Tombigbee 2 & 3	9/78 & 6/79	Spray tower	CS[b] lined with Resista-Flake 1151[c]; 316 SS wash tray	
Arizona Elec. Power Coop. Apache 2 & 3	2/79 & 6/79	Packed tower	CS lined with Coroline 505AR and Flakeline 103; FRP beams to support polypropylene packing	FRP beams replaced with 316L SS for added strength
Arizona Public Service Cholla 1	12/73	Packed tower (one module is not packed)	316L SS	Pitting and corrosion of SS; Coroline 505AR lining added in areas wet by scrubbing liquor; lining eroded and debonded
Cholla 2	5/78	Packed tower	CS lined with Coroline 505AR and Flakeline 103; 316L SS support beams	
Central Illinois Light Duck Creek	7/76	Ventri-Sorber®	316L SS and Hastelloy G at top	
Columbus & Southern Ohio Elec. Conesville 5 & 6	1/77 & 4/78	TCA (1 stage)	CS lined with 1/4 in. (6 mm) neoprene; rubber clad supports; FRP dividers; plastic balls; FRP trap out tray	Some lining replacement; fire in one module of Unit 5; plastic balls failed and replaced by rubber balls
Commonwealth Edison Will County 1	2/72	Tray tower (2 stages)	CS lined with 3/16 in. (5 mm) natural gum rubber; 316 SS trays	
Duquesne Light Elrama	10/75	Venturi	CS lined with Flakline 103; brick over the lining at top of ME area; 316L SS at top of cone under bull nozzle	Flakeline 103 failed when change was made to high Mg lime; lining replaced with Coroline 505AR which was also used to replace 316L SS on top of cone because of abrasion
Phillips	7/73	Venturi	Same as Elrama	Same as Elrama
Indianapolis Power & Light Petersburg 3	12/77	TCA (3 stages)	CS lined with neoprene; neoprene clad CS supports; FRP dividers; rubber and plastic balls; FRP trap out tray	
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	Marble bed (1 stage)	CS lined with unidentified organic lining; 316L SS internal support and dividers; FRP drain pots	Lining failed in lower portion which was relined with 316L SS; upper portion [4 ft (1.2 m) above bed] has original lining which needs repair; drain pots replaced with 316LSS
La Cygne 1	6/73	Tray tower (2 stages)	316L SS vessel and sieve trays; bottom of sump lined with Kaocrete	Some patchwork on Kaocrete in one sump
Kansas Power & Light Lawrence 4 & 5 (old)	10/68 & 9/71	Marble bed (1 stage)	CS lined with organic linings; 316L SS supports and 316L SS drain pots with FRP base	Relined several times; no lining provided both the abrasion and corrosion resistance needed
Lawrence 4 & 5 (new)	1/77 & 4/78	Spray tower	316L SS; FRP bulk entrainment separator	
Kentucky Utilities Green River	9/75	Mobile bed	CS lined with Pre-Krete G-8 below bed; 316 SS from bed to top of ME; CS lined with Carboline lining above ME	Carboline lining failed and replaced with Pre-Krete
Louisville Gas & Electric Cane Run 4	8/76	Mobile bed	CS lined with Pre-Krete; 316L SS cages and rubber balls	Sponge rubber balls "pruned up" and were replaced with different type
Cane Run 5	12/77	Spray tower	CS lined with Flakeline 252; 316 SS impingement plates; FRP bulk entrainment separator	Some repair of eroded areas with Protecto-Flake 500

Table 3-3 (Continued)

Utility and Plant	Start-Up Date	Description of Component	Original Materials	Comments
Mill Creek 3	7/78	Mobile bed	CS lined with Pre-Krete	
Paddy's Run 6	4/73	Marble bed (2 stages)	CS lined with Flakeline 103; 316L SS plates and supports	
Minnkota Power Coop. Milton R. Young 2	5/77	Spray tower	CS lined with Flakeline 103; 316L SS wash tray	Some repair of lining in one area where spray impinged
Montana Power Colstrip 1 & 2	11/75 & 8/76	Venturi and spray zone	CS lined with Rigiflake 4850; 316L SS tray and plumb bob; ARB in throat	Loss of lining adhesion; replace with Plasite 4030 and 4020
Northern States Power Sherburne 1 & 2	5/76 & 4/77	Marble bed (1 stage)	CS lined with Flakeline 151 on Unit 1 and Flakeline 151AR on Unit 2; 316L SS supports and drain pot covers	Lining on Unit 1 has required some patching; lining on Unit 2 debonded between layers and was replaced with Flakeline E in 1978; failure of drain pot covers was solved by annealing
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	Venturi	CS lined with Rigiflake 4850; 316L SS lined with epoxy/glass fiber mat in some areas (throat, liner plates, rings)	Epoxy/glass fiber mat did not adhere to SS and was not replaced
South Carolina Public Service Winyah 2	8/77	Tray tower (1 stage)	CS lined with 3/16 in. natural rubber; 316L SS tray with rubber-clad CS supports	
South Mississippi Elec. Power R. D. Morrow 1 & 2	9/78 & 6/79	Ventri-Sorber®	CS lined with Protecto-Flake 550; ARB on floor and sloping side wall	Refer to footnote[d]
Southern Illinois Power Coop. Marion 4	4/79	Tray tower (2 stages)	316L SS inlet; CS walls lined with Resista-Flake 1103; sump bottom lined with Resista-Flake 1251; 316L SS trays	
Springfield City Utilities Southwest 1	4/77	TCA (3 Stages)	CS lined with neoprene; FRP cage dividers; sponge rubber balls; FRP trap out tray	
Tennessee Valley Authority Widows Creek 8	5/77	Tray tower (5 stages)	Cor-Ten steel lined with neoprene; 316L SS outlet elbow and ME duct; trays alternate between FRP and 316L SS	Rubber debonded in tapered bottom hopper and was replaced with 316L SS lining after 3000 hours; top tray changed from FRP to 316L SS because of erosion
Utah Power & Light Huntington 1	5/78	Spray tower	CS lined with Ceilcrete 2500AR in high abrasion areas and Flakeline 103 elsewhere; ARB brick covering in bottom and 3 ft (1 m) up sides; rubber-clad CS supports	

[a]Any materials problems identified are indicated under comments.

[b]Abbreviations used are:
ARB = acid-resistant brick
CS = carbon steel
FRP = glass-fiber-reinforced plastic
ME = mist eliminator
SS = stainless steel
TCA = Turbulent Contact Absorber.

[c]Trade names of linings are identified in Table 2-2.

[d]The unsupported wall bricks fell off, so only the floor brick remains. There have been some spot failures of the lining, and several pinhole leaks have developed in the absorber wall. The absorber action is achieved by Ventri-rods of Type 316L stainless steel tubes (Riley/Environeering). During July, 1979, problems developed in Unit 1. Partial plugging of the plates beneath the rods and of the mist eliminator led to high velocity flow that eroded away the exposed part of the plates. Stains not yet identified appeared on the Ventri-rods, and a number of the rods below the spray nozzles have been completely worn through.

combination of materials. Nevertheless, they are discussed below according to the major materials category used in construction; e.g., stainless steel, rubber-lined carbon steel, organic-lined carbon steel, and ceramic-lined carbon steel.

Stainless Steel Absorbers

Stainless steel (Type 316L) construction has been the choice for the absorbers at Cholla 1, Duck Creek, La Cygne, and the new systems at Lawrence 4 and 5, as well as a section of the absorber vessel at Green River. This construction requires the highest initial investment of the choices available, but has been selected by some with the belief that it will require less maintenance, and also less down time than other materials choices. Moreover, weld patching and replacement of new plates can be much easier and quicker than a reapplication of a lining. Type 316L stainless steel components such as trays, plates, supports, and fasteners have been used in many other absorbers. It is recognized, however, that high chlorides can present a corrosion problem, and abrasion by scrubber slurries can sometimes cause wear failures. The operating experience thus far ranges from 1-1/2 years at Lawrence (Unit 5) to 6-1/2 years at La Cygne; both units are still in service although some patches have been made in the stainless steel sidewalls of the new absorbers at Lawrence.

The only problems reported were at Cholla 1 where corrosion and pitting of the stainless steel occurred because of the relatively high chloride content (2,000 ppm) of the scrubbing liquor. The slurry from the prescrubber at Cholla is removed from the gas stream entering the absorber tower by means of a centrifugal plate separator containing a conical hat. This unit is located in the bottom of each absorber tower. Areas wetted by the prescrubber slurry (lower part of absorber) have undergone pitting and crevice corrosion which is approximately equal in severity to that observed in the prescrubber. Areas in the bottom of the towers were repaired with an epoxy lining (Coroline 505AR) which has exhibited debonding and erosion. In contrast, areas wetted by the absorber slurry (upper part of absorber) have undergone much less severe attack although significant buildup of solids is observed. The better performance of the Type 316L stainless steel in the latter application is thought to be the result of the lower Cl^- concentration and higher pH (about 6.5) found in the absorber slurry. Type 316L stainless steel is not recommended for service in a low pH and high chloride environment.

Rubber-Lined Absorbers

Rubber linings for carbon steel provide a construction material for absorbers which is intermediate in price between stainless steel and carbon steel protected with organic linings. Both natural (gum) rubber and neoprene have been used. Natural rubber is superior to neoprene in both abrasion and chemical resistance, but neoprene is less flammable. The rubber is applied in sheets which are bonded to the steel with adhesive. Care must be taken in lapping the rubber because the laps are the areas most subject to failure by debonding. Thus, it is extremely important that the rubber be lapped so that liquids flowing over the surface do not get under the lap. Disadvantages in rubber linings are difficulty of repair and the possibility of fires caused by welders' torches. Besides having excellent resistance to the chemicals in the gas and slurry, rubber is outstanding in abrasion resistance. Because rubber provides such a high degree of abrasion resistance it might be used to advantage in localized, high-abrasion areas in absorbers. This has been done at Tombigbee, where a natural rubber lining is used in the spray zone.

The absorbers at Conesville, Petersburg, Southwest, and Widows Creek are constructed primarily of neoprene-lined steel, while the absorbers at Will County and Winyah are constructed primarily of natural rubber-lined steel. At Conesville, incorrect lapping in an area of one absorber caused problems until the lining was replaced with proper lapping. After 7,000 hours of operation at Widows Creek, the neoprene lining in the tapered hopper bottom portion of the absorbers debonded and was replaced with a Type 316L stainless steel liner. Also, sparks from a welder's torch have caused the neoprene lining to catch fire at Conesville and Widows Creek. The longest operating experience thus far has been about 8 years at Will County where the linings are still in service.

Organic-Lined Absorbers

Organic linings over carbon steel provide the lowest initial cost of construction. The performance of lined carbon steel has varied from satisfactory to poor. There are a number of reasons for the variation in performance including the selection of marginal linings in an attempt to economize, and improper application of the linings or inadequate surface preparation. It appears that the lining selection in some of the older FGD systems were poor choices. Little experience was available regarding linings in SO_2 absorbers when the first systems were constructed. Wear from the abrasive slurries is one of the more common causes of failure. In some cases the problem was solved by relining with a more abrasion-resistant material such as a mat-reinforced epoxy lining in place of a glass flake-filled polyester lining. Blistering and debonding of the linings have also occurred in some cases; in at least one instance, poor application was cited as the probable cause.

Several absorbers as outlined below are in operation with their original organic linings. The only problems reported were at Sherburne 1 where some patching was required, Milton R. Young where some repair was required in the areas of spray impingement, and R. D. Morrow where there have been spot failures of the lining and several pinhole leaks have developed in the absorber wall. The longest period of successful performance thus far is at Paddy's Run where the lining has experienced more than 22,000 hours of actual operating time and is still in service.

Plant and Lining	Length of Service (years)
Mica Flake/Polyester	
Sherburne 1 - Flakeline 151	3-1/2
Glass Flake/Polyester and Mica Flake Polyester	
Marion 4 - Resista-Flake 1103 and 1251	1/2
Tombigbee 2 and 3 - Resista-Flake 1151	1-1/2 and 1/2
Cane Run 5 - Flakeline 252 (some repair of eroded areas with Protecto-Flake 500)	2
Glass Flake/Polyester	
Paddy's Run 6 - Flakeline 103	6-1/2
Milton R. Young 2 - Flakeline 103	2-1/2
Bruce Mansfield 1 and 2 - Rigiflake 4850	3-1/2 and 2-1/2
R. D. Morrow 1 and 2 - Protecto-Flake 550 (chlorinated polyester)	1-1/2 and 1/2
Glass Flake/Polyester and Mat-Reinforced Linings	
Cholla 2 - Flakeline 103 and Coroline 505AR (epoxy)	1-1/2
Apache 2 and 3 - Flakeline 103 and Coroline 505AR (epoxy)	1 and 1/2
Huntington 1 - Flakeline 103 and Ceilcrete 2500AR (polyester)	1-1/2

Some of the organic linings in absorbers have required replacement. The old units at Lawrence were relined several times with various linings, none of which provided both the abrasion resistance and chemical resistance needed. The absorbers were rebuilt with Type 316L stainless steel. An unidentified epoxy lining failed at Green River and Cane Run 4 (above the mist eliminator) and was replaced by Pre-Krete in the former case and by an inert flake-filled vinyl ester (Plasite 4005) in the latter case. A mica flake-filled polyester lining (Flakeline 151AR) at Sherburne 2 debonded between layers resulting in bubbles and blisters. The lining was replaced with an inert flake-filled epoxy (Flakeline E). There have been at least three cases where a glass flake-filled polyester lining had to be replaced. At Hawthorn, the lining (trade name unavailable) failed because of high temperature and low pH excursions, as well as damage from welding early in the operation. The absorbers were relined with Type 316L stainless steel. At Elrama and Phillips, Flakeline 103 was replaced with a fiber mat-reinforced, heavy duty epoxy lining (Coroline 505AR) because of excessive abrasion. At Colstrip, poor adhesion of Rigiflake 4850 caused by improper application led to replacement by inert flake-filled vinyl ester linings (Plasite 4030 and 4020). It is interesting to note that at Hawthorn, Elrama, Phillips, and Colstrip, the SO_2 absorber is also the primary fly ash removal device. Although a glass flake-filled polyester lining failed in each of these cases, excessive abrasion is not always cited as the cause of failure.

While linings have been used in many absorbers, the time in service in most instances has been too short to obtain an effective appraisal of their performance. From the information available at present, certain conclusions are possible regarding the use of organic linings. They are as follows:

- A high-quality lining material should be selected. The minimum quality of lining used in absorbers should be (a) the trowel-applied, glass flake/polyester of 80 mil (2 mm) nominal thickness in areas subject to normal abrasion, and (b) the heavy duty (1/8-inch nominal thickness; 3 mm) fiber mat-reinforced materials containing abrasion-resistant fillers in the high-abrasion areas (wherever slurry is projected against the lining).

- The lining material must be applied by skilled, experienced applicators who will stand by their work.

- The applicator must understand metal surface preparation procedures and employ them properly.

- Careful quality control procedures must be used.

Ceramic and Inorganic Linings in Absorbers

Although very few absorbers have been constructed of ceramic-lined carbon steel, many have used some type of ceramic lining or inorganic lining at specific high-abrasion areas such as venturi throats and sumps. The use of ceramics has been limited because of high cost, high weight, and sometimes the problems caused by brittleness. The absorbers at Cane Run 4 and Mill Creek have Pre-Krete linings, while the absorber at Green River is lined with Pre-Krete below the mobile bed and above the mist eliminator. The bottom of the absorber sumps at La Cygne and Winyah are lined with Kaocrete. Acid-resistant brick is used to protect the bottom section of the absorbers at Huntington and R. D. Morrow. In the former case, the bottom of the absorber is used as the reaction tank. At Elrama and Phillips, acid-resistant brick is used to cover the inclined surface just below the venturi throat. Generally, good performance has been reported for the ceramic linings, including 4-1/2 years and 6-1/2 years of operation thus far at Green River and La Cygne, respectively.

SPRAY NOZZLES

Spray nozzles are used to deliver the scrubbing liquor to the prescrubber and absorber, and the wash water to the mist eliminator. The function of the spray nozzles is to disperse the liquid under pressure as a stream of fine droplets. The spray nozzles are located inside the prescrubber and absorber vessels and are therefore exposed to the same environment as the vessel internals. The prescrubber and absorber spray nozzles handle lime or limestone slurry which may contain considerable amounts of fly ash if wet particulate collection is used or if the dry collection device is inefficient. The mist eliminator wash nozzles usually handle makeup water and/or reclaimed water (thickener or pond overflow) and, therefore, should be much less susceptible to internal abrasion than the former nozzles.

Information on materials of construction for spray nozzles is compiled in Table 3-4. A wide variety of materials, ranging from plastic (Noryl® resin) to extremely hard Al_2O_3 (alumina) and SiC (silicon carbide) have been used for spray nozzles. Wear, pluggage, and installation problems are the only difficulties reported for this component. Wear problems were identified only for plastic nozzles (Duck Creek, Hawthorn, and old Lawrence 4 and 5) and metallic nozzles (Cholla 1, Hawthorn, La Cygne, Southwest, and Widows Creek). Only one of these installations, Duck Creek, cited problems with mist eliminator wash nozzles. Although makeup water is used to wash the mist eliminators at Duck Creek,

Table 3-4

SPRAY NOZZLES--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Original Materials: Prescrubber Spray Nozzles	Original Materials: Absorber Spray Nozzles	Original Materials: ME Wash Spray Nozzles	Comments
Alabama Electric Coop. Tombigbee 2 & 3	9/78 & 6/79	SiC (Refrax)	SiC (Refrax)	Stellite tips	Plugging eliminated with strainer
Arizona Electric Power Coop. Apache 2 & 3	2/79 & 6/79	No prescrubber	316L SS[b]	316L SS	
Arizona Public Service Cholla 1	12/73	316L SS	316L SS	Not identified	Some erosion
Cholla 2	5/78	317L SS	317L SS	Not identified	
Central Illinois Light Duck Creek	7/76	No prescrubber	Al_2O_3	PVC	Al_2O_3 slurry nozzles plugged and were replaced with 316L SS pipe nipples; PVC wash nozzles wore out in 1 week and were replaced with Al_2O_3
Columbus & Southern Ohio Elec. Conesville 5 & 6	1/77 & 4/78	Carpenter 20	SiC	Carpenter 20	Plugging is only problem
Commonwealth Edison Will County 1	2/72	316L SS	316L SS	316L SS	Some erosive wear but original nozzles still in service
Duquesne Light Elrama	10/75	No prescrubber	316L SS	316L SS	
Phillips	7/73	No prescrubber	316L SS	316L SS	
Indianapolis Power & Light Petersburg 3	12/77	Carpenter 20	SiC (Refrax)	Carpenter 20	
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	No prescrubber	FRP	Not identified	FRP and galvanized steel failed; Coors Al_2O_3 broke when plugged or dropped but wore well; now using 316L SS which lasts 6 to 12 months
La Cygne 1	6/73	SS	SS	316 SS	Prescrubber and absorber nozzles wore out and were replaced with Al_2O_3 nozzles (pink)
Kansas Power & Light Lawrence 4 & 5 (old)	10/68 & 9/71	No prescruber	Plastic	Not identified	Erosion of swirl vanes required considerable maintenance
Lawrence 4 (new)	1/77	Not identified	Al_2O_3	Not identified	
Lawrence 5 (new)	4/78	Not identified	SiC	Not identified	
Kentucky Utilities Green River	9/75	Stellite	Various	SS	Plastic, SiC, and SS all plugged; slurry now discharged through FRP pipe nipples
Louisville Gas & Electric Cane Run 4	8/76	Not identified	Plastic	Not identified	Spin vanes failed; replaced with Al_2O_3 nozzles which gave excessive ΔP; 316 SS nozzles now used on top header; FRP pipe nipples only on bottom header
Cane Run 5	12/77	No prescrubber	SiC	Not identified	
Mill Creek 3	7/78	Not identified	Not identified	Not identified	
Paddy's Run 6	4/73	No prescrubber	Rubber-lined plastic	Not identified	Plastic spinners replaced in 4/77
Minnkota Power Coop. Milton R. Young 2	5/77	No prescrubber	Al_2O_3	316L SS	
Montana Power Colstrip 1 & 2	11/75 & 8/76	No prescrubber	Al_2O_3 and	316L SS	Al_2O_3 for slurry spray; 316L SS for venturi wall and absorber tray

Table 3-4 (CONTINUED)

Utility and Plant	Start-Up Date	Original Materials: Prescrubber Spray Nozzles	Absorber Spray Nozzles	ME Wash Spray Nozzles	Comments
Northern States Power Sherburne 1 & 2	5/76 & 4/77	Al_2O_3	Noryl®	Not identified	Absorber nozzles plugged and were replaced with Al_2O_3
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	No nozzles	316L SS with	Not identified	Rigiflake 413GS cladding wore off repeatedly; nozzles have been used unclad without problems
South Carolina Public Service Winyah 2	8/77	316L SS	316L SS	316L SS	Some plugging problems
South Mississippi Elec. Power R. D. Morrow 1 & 2	9/78 & 6/79	No prescrubber	Hastelloy G	Al_2O_3	
Southern Illinois Power Coop. Marion 4	4/79	316L SS	316L SS	316L SS	
Springfield City Utilities Southwest 1	4/77	Carpenter 20	Sic (Refrax)	Carpenter 20	Some wear of Carpenter 20 nozzles in prescrubber
Tennessee Valley Authority Widows Creek 8	5/77	316L SS	316L SS	316L SS	Erosion causes frequent replacement; other materials being considered
Utah Power & Light Huntington 1	5/78	No prescrubber	SiC (Refrax)	316L SS	

[a]Any materials problems identified are indicated under comments.

[b]Abbreviations used are:
FRP = glass-fiber-reinforced plastic
PVC = polyvinyl chloride
SS = stainless steel.

polyvinyl chloride nozzles wore out in one week and were replaced with Al_2O_3 nozzles. A possible explanation for the failure is that the wash water for the second-stage mist eliminator is reused to wash the first stage and thus has the opportunity to pick up solids which can cause nozzle erosion. The remaining installations mentioned above cited problems with prescrubber and/or absorber spray nozzles. All of these installations utilize wet particulate removal with the exception of Widows Creek and Southwest; however, the electrostatic precipitator at the former installation is inefficient. The reason for the wear of the Carpenter 20 prescrubber spray nozzles at Southwest is not readily apparent, but Carpenter 20 is not as abrasion resistant as Type 316L stainless steel which is more commonly used. Carpenter 20 was selected at Southwest to provide corrosion protection against a chloride content of about 4,650 ppm in the scrubbing liquor. Wear problems are more common on nozzles used in limestone slurry systems rather than in lime slurry systems. However, almost 8 years of service has been obtained from Type 316L stainless steel nozzles using limestone at Will County, even with wet particulate removal at this installation. The spray nozzle pressure drop is 10 psi (69,000 Pa) in the venturi prescrubbers and 5 psi (34,500 Pa) in the absorbers at Will County. After 7 to 8 years of operation, the tips had to be replaced in about 50 percent of the venturi nozzles, but in none of the absorber nozzles. This experience indicates that better materials performance for these spray nozzles may be related to lower nozzle pressures.

The Type 316L stainless steel absorber spray nozzles at Bruce Mansfield were originally lined with a glass fiber mat reinforced epoxy (Rigiflake 413GS) because of the belief that chlorides might corrode the stainless steel. The lining wore off repeatedly and it was not possible to achieve a reliable bond to the nozzle surface so that the idea of a protective lining was abandoned. No problems have been encountered with the unlined nozzles.

Pluggage problems have occurred with all types of materials, and can contribute to "spin off" of threaded ceramic nozzles or failure of spin vanes from "hammering". Strainers have been used to solve pluggage problems at Tombigbee but other units have found that nozzles can be eliminated and pipe nipples used instead (Green River, Cane Run 4, and Duck Creek).

Wear problems have not been reported for any ceramic nozzles. However, handling or installation features are important for these nozzles. To prevent breakage during assembly, utilities use rubber thrust washers with threaded nozzles, or utilize flanged nozzles. With either type, damage can occur from tools dropped during maintenance periods, or from improper care in unplugging clogged nozzles, particularly those with spin vanes.

In spite of greater care required to install them, ceramic nozzles are now becoming commonly used for slurry service in the newer scrubber systems. Both SiC and Al_2O_3 materials should provide good erosion resistance. Cost, availability, and design considerations will probably influence the selection of a specific material more than any difference in wear resistance. Stainless steel nozzles appear to be preferred for mist eliminator service, but ceramic nozzles are used there also (Al_2O_3 at R. D. Morrow).

MIST ELIMINATORS

A mist eliminator in a lime or limestone FGD system is a device employed to collect, remove, and return to the scrubbing liquor the slurry droplets which are entrained with flue gas exiting the absorber. In a few cases, a mist eliminator is also used to remove droplets from the flue gas exiting the prescrubber. The mist eliminator is usually located inside the absorber (or prescrubber) vessel near the gas exit and is therefore subject to the same environmental conditions as the vessel internals. However, the mist eliminator must also be able to withstand the high pressure water sprays that are used to wash away deposits.

Practically all of the mist eliminators in use are chevron-type with a variety of vane shapes. Various measures have been implemented to reduce plugging of mist eliminators or improve washing effectiveness to reduce scaling. Some suppliers have installed wash or knock-out trays. This provides a means to recycle the relatively clean mist eliminator wash water and allows increased water flow rate, as well as greater flexibility in washing operations. Another effective method has been to design the equipment to provide flue gas flow in a horizontal direction at the mist eliminator.

The vanes are most often constructed of some form of plastic with or without fiberglass reinforcement, but alloys have also been used. Information on materials of construction for mist eliminators is compiled in Table 3-5. Frequently the material is described simply as FRP (glass-fiber-reinforced plastic). While the plastic in the FRP is not specified in many cases, it is most likely a polyester, which is the same kind of plastic used in FRP piping as well as many of the glass flake-reinforced lining materials. However, vinyl ester, polypropylene, and Noryl® (polyphenylene oxide) plastic have also been used in FRP mist eliminator vanes. To make FRP, layers of glass fabric are laid between layers of

Table 3-5

MIST ELIMINATORS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Description of Component	Original Materials	Comments
Alabama Electric Coop.				
Tombigbee 2 & 3	9/78 & 6/79	Horizontal chevron (1 stage)	Noryl®	Operational problems caused overheating and warped ME; replaced in Unit 2 with same material
Arizona Electric Power Coop.				
Apache 2 & 3	2/79 & 6/79	A-frame chevron and horizontal chevron (2 stages)	Polypropylene	
Arizona Public Service				
Cholla 1	12/73	Cyclonic ME between prescrubber and absorber	316L SS[b]	Corrosion problems because of high chloride concentrations
		Horizontal chevron (2 stages)	Polypropylene	
Cholla 2	5/78	Cyclonic ME between prescrubber and absorber	CS lined with Coroline 505AR (mat-reinforced epoxy)	
		A-frame chevron and horizontal chevron (2 stages)	Polypropylene	
Central Illinois Light				
Duck Creek	7/76	Slanted chevron; 30 to 40 degrees with vertical (2 stages)	Hastelloy G	
Columbus & Southern Ohio Elec.				
Convesville 5 & 6	1/77 & 4/78	Horizontal chevron (2 stages)	FRP	Breakage during cleaning from striking with hammer
Commonwealth Edison				
Will County 1	2/72	Horizontal chevron (2 stages)	FRP with Hetron® 197 resin (chlorinated polyester)	Original ME embrittled and was replaced in 1975 with a heavier one of similar material
Duquesne Light				
Elrama	10/75	Horizontal chevron (2 single stage)	FRP	Can be damaged by impact during manual cleaning of scale
Phillips	7/73	Horizontal chevron (2 single stage)	FRP	Mechanical damage during cleaning
Indianapolis Power & Light				
Petersburg 3	12/77	Horizontal chevron (2 stages)	FRP with Hetron® resin (polyester)	
Kansas City Power & Light				
Hawthorn 3 & 4	11/72 & 8/72	A-frame chevron (2 stages)	FRP	
La Cygne 1	6/73	Horizontal chevron (2 stages)	FRP	
Kansas Power & Light				
Lawrence 4 & 5 (old)	10/68 & 9/71	A-frame chevron (2 stages)	FRP	
Lawrence 4 & 5 (new)	1/77 & 4/78	A-frame chevron (2 stages) plus bulk entrainment separator	FRP	

Table 3-5 (CONTINUED)

Utility and Plant	Start-Up Date	Description of Component	Original Materials	Comments
Kentucky Utilities Green River	9/75	Centrifugal vane ME	316L SS	
Louisville Gas & Electric Cane Run 4	8/76	Centrifugal vane ME	316L SS	Replaced with 2-stage (horizontal and A-frame) chevron made of Noryl® because of high pressure drop
Cane Run 5	12/77	A-frame chevron (2 stages) plus bulk entrainment separator	FRP with Noryl® resin (polyphenylene oxide)	
Mill Creek 3	7/78	Horizontal chevron and A-frame chevron (2 stages)	Noryl®	Upper stage (A-frame) warped and/or melted because it was close to reheater; replaced upper stage with 316L SS
Paddy's Run 6	4/73	A-frame chevron (2 stages)	Polypropylene	Color changed but otherwise no problem
Minnkota Power Coop. Milton R. Young 2	5/77	Horizontal chevron (1 stage)	Noryl®	Emergency water spray to prevent overheating
Montana Power Colstrip 1 & 2	11/75 & 8/76	Horizontal chevron (1 stage)	Noryl®	Sagging and melting has required replacement of about 30 percent each year
Northern States Power Sherburne 1 & 2	5/76 & 4/77	A-frame chevron (2 stages)	FRP	Some breakage during cleaning
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	Horizontal chevron (2 single stage)	FRP with polypropylene resin; fire retardant added	Breakage during manual cleaning
South Carolina Public Service Winyah 2	8/77	Horizontal chevron (2 stages)	FRP with Derakane® resin (vinyl ester)	
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	Slanted chevron; 30 to 40 degrees with vertical (2 stages)	Noryl®	Deformed by heat; replaced with FRP with Diamond Shamrock 6694 resin
Southern Illinois Power Coop. Marion 4	4/79	Horizontal chevron (2 stages)	FRP	
Springfield City Utilities Southwest 1	4/77	Horizontal chevron (2 stages)	FRP	ME is not strong enough to support a man's weight so it will be replaced with thicker FRP chevrons
Tennessee Valley Authority Widows Creek 8	5/77	Vertical chevron (1 stage)	316L SS; vanes are 20 gauge	Mud deposits cause low pH environment which results in chloride corrosion; FRP would not have survived the cleaning which has been necessary
Utah Power & Light Huntington 1	5/78	Horizontal chevron (1 stage)	Polypropylene	Breakage when walked on

[a]Any materials problems identified are indicated under comments.

[b]Abbreviations used are:
CS = carbon steel
FRP = glass-fiber-reinforced plastic
ME = mist eliminator
SS = stainless steel.

plastic while in liquid form. The fabric provides reinforcement, rigidity, and strength. Subsequently the plastic solidifies by curing (cross linking of molecules), or by cooling. Some of the mist eliminators are constructed of unreinforced plastic such as Noryl® or polypropylene.

In general, mist eliminators have been satisfactory from the materials standpoint. Problems have been mostly in plugging, which requires frequent cleaning, plus spray washing on a continuous or intermittent basis. The FRP mist eliminators are prone to breakage during cleaning, either from striking with a hammer or from men walking on them. This breakage can be prevented by care in cleaning and by using thick enough FRP. Also, unreinforced plastic mist eliminators are subject to warping, sagging, and/or melting during temperature excursions.

Plastic Mist Eliminators

FRP mist eliminators are used at Hawthorn, La Cygne, Lawrence 4 and 5, Marion, Petersburg, Winyah, and Cane Run 5 with no materials problems reported. Problems with breakage during cleaning have occurred with the FRP mist eliminators at Conesville, Elrama, Phillips, Sherburne, and Bruce Mansfield. At Southwest, the FRP chevrons are not strong enough to support a man's weight so they will be replaced with thicker FRP chevrons. The original FRP mist eliminator at Will County embrittled and was replaced with a heavier one of similar material.

Noryl® (polyphenylene oxide) mist eliminators are used at Tombigbee, Cane Run 4, Mill Creek, Milton R. Young, Colstrip, and R. D. Morrow. All of these installations have reported problems with heat distortion or melting except Cane Run 4 and Milton R. Young. The latter unit has an emergency water spray to prevent overheating. At Mill Creek, the upper level chevrons have been replaced with Type 316L stainless steel, and at R. D. Morrow the chevrons have been replaced with FRP.

Polypropylene mist eliminators are used at Apache, Cholla 1 and 2, Paddy's Run, and Huntington. The only problems reported were a color change at Paddy's Run and breakage when walked on at Huntington. In the latter case, the broken sections have been replaced and planking is now layed across the mist eliminators when they have to be walked on.

Alloy Mist Eliminators

Alloy mist eliminators are used at Duck Creek, Green River, Mill Creek (upper level only), and Widows Creek. All of these are Type 316L stainless steel except for Duck Creek which is Hastelloy G. The mist eliminator at Green River is a centrifugal rather than a chevron type. The only problem reported is at Widows Creek where mud deposits cause a low pH environment which results in chloride corrosion. However, an FRP mist eliminator would not have survived the cleaning which has been necessary.

REHEATERS

The flue gas leaving the absorber unit of an FGD system can be reheated to avoid acid condensation in the stack and to provide buoyancy and low visibility for the plume, or it can be left at the scrubber exit temperature. When reheat is chosen, it has been done by: (1) providing a heat exchanger in the flue gas stream, (2) heating air externally and injecting it into the flue gas, (3) direct combustion at the outlet duct, or (4) bypassing some unscrubbed flue gas and mixing it with the scrubbed gas. Reheaters provide a temperature rise in the range of 20° to 75°F (11° to 42°C) for the scrubbed flue gas. Data on reheater type, temperature rise, and materials of construction are summarized in Table 3-6.

In-Line Reheat

If an in-line reheater is used, it is installed in the absorber vessel or flue gas duct after the mist eliminator, and the heat can be supplied by steam or hot water. The materials of construction for the tubes or coils range from carbon steel to Inconel 625. Acid corrosion from H_2SO_4 condensation is a problem for carbon steel and stress corrosion from chlorides is a problem for the Type 300 series stainless steels. Therefore, the severity of the corrosion problem for the former material is probably related to the concentration of sulfur oxides in the scrubbed flue gas, while for the latter materials it is probably related to the chloride content in the scrubbing liquor that may be carried beyond the mist eliminator. Pluggage of the tube banks is also a problem, particularly if finned tubes are used. Soot blowers are required to maintain performance with in-line reheaters.

Finned carbon steel tubes containing hot water under pressure have been used for reheat at old and new Lawrence 4 and 5, Sherburne, and Hawthorn. The same type of tubes are used with steam at Cane Run 5. Some tube failures occurred at Lawrence after 6 years of operation, but after switching to low sulfur coal there

Table 3-6

REHEATERS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Type of Reheat	Temperature Rise, °F (°C)	Description of Component	Original Materials	Comments
Alabama Electric Coop. Tombigbee 2 & 3	9/78 & 6/79	Bypass	48 (27)	30% bypass to outlet duct	Inconel 625 mixing vane at junction of bypass and outlet ducts	
Arizona Electric Power Coop. Apache 2 & 3	2/79 & 6/79	Bypass	78 (43)	50% bypass to outlet duct	Outlet duct is lined with fluoroelastomer	No reheat when both modules are in use
Arizona Public Service Cholla 1	12/73	In-line	60 (33)	Steam in smooth tubes	316L SS[b]	Tubes need replacement; Incoloy 825 is recommended; baffles installed where tubes meet headers to prevent corrosion
Cholla 2	5/78	In-line	39 (22)	Steam in smooth tubes	Inconel 625 tubes and Uddeholm 904L baffles	
Central Illinois Light Duck Creek	7/76	None				
Columbus & Southern Ohio Elec. Conesville 5 & 6	1/77 & 4/78	None				
Commonwealth Edison Will County 1	2/72	In-line	25 (14)	Steam in smooth tubes	Cor-Ten for top banks and 304L SS for bottom banks	Developed leaks in 6 months; Cor-Ten replaced with CS and 304L SS replaced with 316L SS; CS replaced every year because of pinhole attack; 316L SS replaced every 1.5 years because of stress corrosion
Duquesne Light Elrama	10/75	Direct combustion	25 (14)	Oil burners outside outlet duct		Reheater not used because of poor mixing and burner corrosion
Phillips	7/73	Direct combustion	23 (13)	Oil burners outside outlet duct		Reheater sealed off because of corrosion when not in use
Indianapolis Power & Light Petersburg 3	12/77	Indirect	30 (17)	Steam in smooth tubes	CS	Heat ambient air to mix with flue gas
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	In-line	60 (33)	Hot water in finned tubes	CS	Tubes plugged with deposits from flue gas; replaced with smooth 304L SS tubes which corroded in 6 months; will be changed to 316L SS
La Cygne 1	6/73	In-line	30 (17)	Steam in smooth tubes	304 SS	Replaced with 316L SS because of corrosion but sill last only 2 to 3 years
Kansas Power & Light Lawrence 4 & 5 (old)	10/68 & 9/71	In-line	25 (14)	Hot water in finned tubes	CS	Some tube failures after 6 years
Lawrence 4 & 5 (new)	1/77 & 4/78	In-line	25 (14)	Hot water in finned tubes	CS	No serious problems with low-S coal
Kentucky Utilities Green River	9/75	None				Plan to install indirect hot air reheat
Louisville Gas & Electric Cane Run 4	8/76	Direct combustion	30 (17)	Oil burners outside outlet duct	Refractory chamber and 316L SS duct	Installed in 6/77 after FGD system start-up

Table 3-6 (CONTINUED)

Utility and Plant	Start-Up Date	Type of Reheat	Temperature Rise, °F (°C)	Description of Component	Original Materials	Comments
Cane Run 5	12/77	In-line	25 (14)	Steam in finned tubes	CS	Corrosion required replacement of some tubing; may use more corrosion-resistant material
Mill Creek 3	7/78	In-line	25 (14)	Steam in finned tubes	CS	Being installed after FGD system start-up
Paddy's Run 6	4/73	Direct combustion	45 (25)	Natural gas burner in outlet duct	Cast iron burner	
Minnkota Power Coop. Milton R. Young 2	5/77	Bypass	30 (17)	15% bypass to outlet duct	316 SS reheat bustle	
Montana Power Colstrip 1 & 2	11/75 & 8/76	In-line	60 (33)	Steam in plate coils	Hastelloy G for lower banks and Inconel 625 for upper banks	Only problem is mechanical cracking of outlet line from plate coil because of lack of flexibility
Northern States Power Sherburne 1 & 2	5/76 & 4/77	In-line	40 (22)	Hot water in finned tubes	CS	Some weld failures during early operation; infrequent leaks
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	Direct combustion	40 (22)	Oil burners outside outlet duct	Sauereisen No. 72 lining in chamber	Lining damaged and replaced with castable refractory; burner instability problems led to abandonment of reheat system
South Carolina Public Service Winyah 2	8/77	Bypass	70 (37)	50% bypass to stack		
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	Bypass	62 (34)	38% bypass to outlet duct	Hastelloy G junction on Unit 2	Temperature rise ranges from 0°F (0°C) at low load to 62°F (34°C) at full load
Southern Illinois Power Coop. Marion 4	4/79	None				
Springfield City Utilities Southwest 1	4/77	None				
Tennessee Valley Authority Widows Creek 8	5/77	Indirect	50 (28)	Steam in finned tubes	CS tubes with copper fins	Heat ambient air to mix with flue gas
Utah Power & Light Huntington 1	5/78	Indirect and bypass	20 (11)	Steam in smooth tubes and 10% bypass to outlet duct	CS tubes	

[a]Any materials problems identified are indicated under comments.

[b]Abbreviations used are:
CS = carbon steel
SS = stainless steel.

have been no serious problems, presumably because of less sulfur oxides in the scrubbed flue gas. At Sherburne, which also burns low sulfur coal, four weld failures occurred early in the operation because of excessive stress. Only infrequent leaks have occurred during the past 3-1/2 years since the stress was removed. Corrosion problems after 1-1/2 years of operation required replacement of some tubing at the 180 degree bends at Cane Run 5. Leaks occurred at the tubing welds at this installation which burns high sulfur coal, and consideration is being given to using a more corrosion resistant material for the reheater tubes. The tubes at Hawthorn, which burns mostly low sulfur coal, did not give corrosion problems but plugging with deposits from the flue gas caused them to be replaced with smooth Type 304 stainless steel tubes on one module. The latter tubes corroded (general corrosion) in about 6 months so that a change will be made to smooth Type 316L stainless steel tubes on all four modules.

The system at Hawthorn provides the highest flue gas temperature rise (60°F; 33°C) for hot water reheat, which means that the reheater tube wall temperature is higher than for other systems using this type of reheat. When the heat is supplied by hot water, the inside tube wall temperature is relatively low (230° to 350°F; 110° to 177°C), while with steam, the wall temperature is in the range of 450° to 650°F (232° to 343°C). Carbon steel tubes may be more resistant to general corrosion in a hot water system than in a steam system because of the lower tube temperature in the case of the former. The rate of corrosion generally increases as the surface temperature increases at constant acid concentration. Perhaps for this reason, alloy tubes are usually used when the heat is supplied by steam.

At Will County, steam in smooth tubes is used for reheat. The top tube banks were originally Cor-Ten steel and the bottom Type 304L stainless steel. Leaks developed in 6 months and the tube banks were replaced with carbon steel and Type 316L stainless steel, respectively. Pinhole attack on the carbon steel requires tube replacement every year, and stress-corrosion cracking of the stainless steel, every 1-1/2 years. No remedial measures are planned since the flue gas cleaning system, which is now used for particulate removal only, may be replaced by an electrostatic precipitator.

Smooth Type 316L stainless steel tubes containing steam are also used for reheat at Cholla 1 and La Cygne. At the former installation, the tubes need replacement after 6 years of operation because of corrosion. At the latter installation, the tubes are a replacement for Type 304 stainless steel which failed because of corrosion, but the Type 316L lasts for only 2 to 3 years.

Inconel 625 tubes with Uddeholm 904L baffles are used at Cholla 2, and Hastelloy G and Inconel 625 plate coils are used at Colstrip without any corrosion problems after 1-1/2 and 4 years, respectively.

Indirect Reheat

In the indirect method of reheat, air is heated separately from the scrubber system, and the corrosion and fouling problems are circumvented. However, additional fan capacity and large space requirements are the disadvantages of this system. Carbon steel steam coils are used at Petersburg, Widows Creek (tubes have copper fins), and Huntington (also has bypass reheat) without any materials problems. The longest operating experience thus far is 2-1/2 years at Widows Creek where operation is continuing.

Direct Combustion Reheat

For direct combustion reheat, oil or gas is burned and the combustion product gas is mixed with the scrubbed flue gas to raise its temperature. Oil burners outside the outlet duct have been installed at Cane Run 4, Elrama, Phillips, and Bruce Mansfield; however, they have been removed or abandoned at the latter three locations. The problems included flame instability, burner corrosion, refractory lining failure, and poor mixing. At Cane Run 4, No. 2 fuel oil is burned in a refractory chamber and the combustion gas is transported in a Type 316L stainless steel duct. Paddy's Run has a natural gas burner made of cast iron and located directly in the outlet duct. No materials problems with the reheaters have been reported at the latter two installations.

Bypass Reheat

Where the entire flue gas output does not have to be scrubbed to meet emission regulations, partial bypass can be used as a reheat method. This approach has been used at Tombigbee, Apache, Milton R. Young, Winyah, R. D. Morrow, and Huntington. Materials problems associated with bypass reheat are included in the section on outlet ducts.

No Reheat

The stations which use no reheat and send the flue gas to the stack at the absorber exit temperature are Duck Creek, Conesville, Green River, Marion, and

Southwest. In some cases, lack of reheat has caused problems with the stack linings. These problems are discussed in the section on stacks. There are plans to install indirect hot air reheat at Green River to protect the stack and reduce plume visibility.

FANS

Fans are inserted in the flue gas stream of FGD systems to drive the flue gas through the system components and out the stack, i.e., to overcome the gas-side pressure losses. The fans can be located either upstream (hot side) or downstream (wet side) from the prescrubber and/or absorber. In the former case, the absorber operates under slight positive pressure, while in the latter case, the absorber operates under slight negative pressure. Information on the materials of construction for fans in lime/limestone FGD systems is summarized in Table 3-7. Except for difficulties encountered at a few sites as discussed below, fans associated with FGD systems have not been a source of problems.

Dry Fans

The majority of the fans associated with FGD systems are located upstream of the absorber unit. Hence these fans operate on the hot flue gases and can be constructed of ordinary carbon steel. At Cholla 1, Cor-Ten steel is used. In some cases these hot-side fans have been eroded by the fly ash in the flue gas stream, particularly if the electrostatic precipitators are not operating at maximum efficiency. This has occurred at Widows Creek where erosion has required rotor replacement every 10 weeks even though these are chromium carbide wear plates. Also, at Green River there is no electrostatic precipitator and fly ash erosion has required flame-spray repairs of the fan. Flame spraying involves passing powdered metal through a heat gun to melt the metal and deposit it on a surface. At Cholla 1, where the fan is preceded by a mechanical fly ash collector, Cor-Ten steel wear plates were added to the ends of the fan blades because of abrasion. The plates were added during the third year of service and prolonged the fan life to about 7 years.

Wet Fans

Several stations have the fans downstream of the absorber. Corrosion-resistant alloys are required if the fans are exposed to the wet flue gas at the absorber exit temperature. However, if the fans are located after the reheater, less-resistant materials are used, particularly if the exit sulfur oxide concentrations are low. The fans are located after the reheaters at Cholla 2, Will

Table 3-7

FANS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Location of Fans	Original Materials	Comments
Alabama Electric Coop.				
Tombigbee 2 & 3	9/78 & 6/79	Between ESP and absorber	Carbon steel	
Arizona Electric Power Coop.				
Apache 2 & 3	2/79 & 6/79	Upstream from absorber	Carbon steel	
Arizona Public Service				
Cholla 1	12/73	Between multiclone and prescrubber	Cor-Ten steel	Fly ash abrasion caused wear of rotor; Cor-Ten wear plates added to ends of blades
Cholla 2	5/78	Between multiclone and prescrubber	Not identified	
		Between reheater and stack	Rubber-lined carbon steel housings and stainless steel blades	
Central Illinois Light				
Duck Creek	7/76	Between ESP and absorber	Carbon steel	
Columbus & Southern Ohio Elec.				
Conesville 5 & 6	1/77 & 4/78	Between ESP and absorber	Carbon steel (A 514-517)	
Commonwealth Edison				
Will County 1	2/72	Between reheater and stack	Existing carbon steel ID fans and new Cor-Ten steel booster fans	
Duquesne Light				
Elrama	10/75	Between mist eliminators	Carpenter 20 rotors with Inconel welds; rubber-lined carbon steel housing	Fans are sprayed with fresh water; wear plates of Carpenter 20 on the rotor tips last about 25,000 rubber lining lasts about 20,000 hours; replacement with Inconel is planned
Phillips	7/73	Between mist eliminators	Same as Elrama	Same as Elrama
Indianapolis Power & Light				
Petersburg 3	12/77	Between ESP and absorber	Carbon steel	
Kansas City Power & Light				
Hawthorn 3 & 4	11/72 & 8/72	Between reheater and stack	Cor-Ten steel	Some fan problems have been related to the FGD system; fans were replaced in 1979
La Cygne 1	6/73	Between reheater and stack	Carbon steel; some with a polymer cladding and some with Inconel 625 rotors; some blades have Inconel clips	Corrosion and erosion problems since start-up; fans are washed every 4 days to remove deposits from absorber carryover
Kansas Power & Light				
Lawrence 4 & 5 (old)	10/68 & 9/71	Between reheater and stack	Carbon steel	No major problems in 7 years of operation
Lawrence 4 (new)	1/77	Between reheater and stack	Cor-Ten steel	
Lawrence 5 (new)	4/78	Between reheater and stack	Carbon steel with rotors of SSS-100 by U.S. Steel	Original fans with new rotors
Kentucky Utilities				
Green River	9/75	Ahead of prescrubber	Carbon steel	Fly ash erosion required flame-spray repairs of fan
Louisville Gas & Electric				
Cane Run 4	8/76	Between ESP and quencher	Carbon steel	Two existing ID fans and 2 booster fans
Cane Run 5	12/77	Between reheater and stack	Carbon steel	
Mill Creek 3	7/78	Between ESP and quencher	Carbon steel	
Paddy's Run 6	4/73	Between reheater and stack	Carbon steel	

Table 3-7 (CONTINUED)

Utility and Plant	Start-Up Date	Location of Fans	Original Materials	Comments
Minnkota Power Coop. Milton R. Young 2	5/77	Between ESP and absorber	Carbon steel	Booster fans in series with ID fans
Montana Power Colstrip 1 & 2	11/75 & 8/76	Between reheater and stack	Carbon steel with a Cor-Ten center plate and rubber-lined housing	Weld defects have required some new center plates; some patching of rubber linings; linings are being replaced with chlorobutyl rubber
Northern States Power Sherburne 1 & 2	5/76 & 4/77	Between reheater and stack	Carbon steel	Have required washing only 2 or 3 times
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	Between prescrubber and absorber	Inconel 625 rotors and rubber-lined carbon steel housings	Impingement of loosened duct deposits damaged rubber lining; Incoloy 825 lining was welded to one housing; new housings of Incoloy 825 are being fabricated
South Carolina Public Service Winyah 2	8/77	Between ESP and quencher	Carbon steel	
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	Upstream from absorber	Carbon steel	
Southern Illinois Power Coop. Marion 4	4/79	Between ESP and quencher	Carbon steel	
Springfield City Utilities Southwest 1	4/77	Between ESP and absorber	Carbon steel	
Tennessee Valley Authority Widows Creek 8	5/77	Between ESP and prescrubber	Carbon steel with chromium carbide wear plates on the blades	High fly ash loading and high blade tip speed causes abrasion failure of the blades in 8 to 13 weeks; abrasion of housing is also observed; one of 4 rotors must be replaced every 10 weeks
Utah Power & Light Huntington 1	5/78	Between ESP and absorber	Carbon steel	

[a]Any materials problems identified are indicated under comments.

County, Hawthorn, La Cygne, Lawrence, Cane Run 5, Paddy's Run, Colstrip, and Sherburne. Several of these fans are constructed of carbon steel, including those at old Lawrence 4 and 5, where there were no major problems in more than 7 years of operation. The booster fans at Will County and the fans at Hawthorn and new Lawrence 4 are constructed of Cor-Ten steel. Some fan problems at Hawthorn have been related to the FGD system and the fans were replaced in 1979. The problems consist of buildup of wet materials on the fan blades due to condensation and deposition of residual particulates so that the fan must be taken off line and washed. When a fan is idle because one module is down, the buildup is nonuniformly distributed and the fan is thrown out of balance. There are rubber-lined fan housings and stainless steel fan blades at Cholla 2, some polymer coatings and some Inconel 625 rotors at La Cygne, and Cor-Ten steel center plates and rubber-lined housings at Colstrip. At La Cygne, there have been corrosion and erosion problems since start-up. These fans are washed every 4 days or whenever the vibration reaches 12 mils (0.30 mm), whichever comes first, to keep the fans in balance by removing deposits caused by particulate carryover from the absorbers.

Wet fans are used at Elrama, Phillips, and Bruce Mansfield. The fans at the latter installation are unique in that they are located between the prescrubbers and the absorbers. At Elrama and Phillips, the rotors are Carpenter 20 with Inconel welds. Wear plates of Carpenter 20 on the rotor tips last about 25,000 hours. The housings are rubber-lined carbon steel and last about 20,000 hours; replacement with Inconel is planned. The Inconel 625 rotors at Bruce Mansfield have performed well. However, impingement of loosened duct deposits damaged the rubber-lined housings, so that Incoloy 825 was welded to the housings for protection. New housings fabricated of Incoloy 825 are planned.

DUCTS

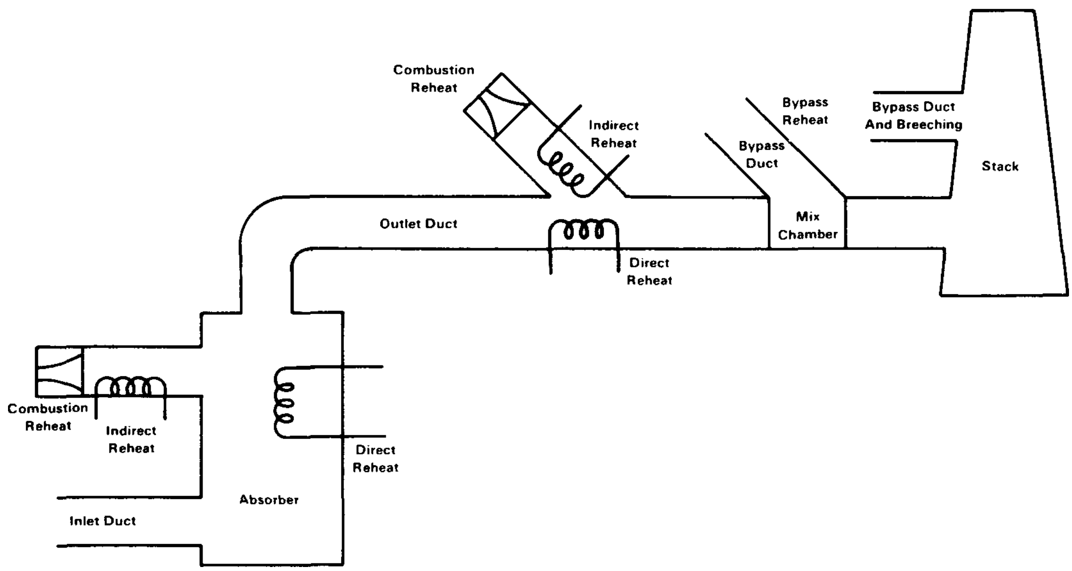
Ducts are used to transport the flue gas in an FGD system. The inlet duct carries the flue gas from the air preheater or electrostatic precipitator to the prescrubber or absorber and is thus exposed to hot flue gas at about 300°F (149°C). The outlet duct carries the flue gas from the absorber to the stack and is thus exposed to saturated (wet) flue gas at about 125°F (52°C) and/or reheated flue gas depending upon the existence and location of the reheater. Part of the outlet duct may also be exposed to hot flue gas during periods of shut down of the FGD system if a bypass duct joins the outlet duct ahead of the stack. The bypass duct carries hot flue gas (about 300°F; 149°C) from the inlet duct to the outlet duct during shut down periods and for reheat if bypass reheat is used.

Since the location of the reheat system determines whether a section of outlet duct is wet or dry, Figure 3-1 has been prepared to summarize the type and location of the reheat systems as well as the existence and location of bypass ducts. More detailed information on reheat systems including the amount of reheat provided can be found in Table 3-6 in the section on reheaters. Figure 3-1 may be needed to understand some of the comments made in Table 3-8 on duct materials, and to know the reason for listing a station under more than one "operating condition" in Table 3-9 which is a condensed performance summary of outlet duct materials.

Inlet and bypass ducts are generally not a major problem area for utilities with scrubbers. However, the outlet duct has been a major problem area, particularly for units which have duct sections which handle both hot gas and wet gas. These sections are for the most part downstream from the bypass junction on units which do not have reheat. Acidic conditions developed during scrubber operation become more severe on bypass as the temperature is raised and other corrosive species in the unscrubbed flue gas (chloride and fluoride) are introduced. Because of the critical nature of the outlet duct in this area (a failure requires shut down of the boiler), utilities will be demanding the use of long lasting alloys and/or linings in this zone, and probably upstream from the outlet dampers of both the bypass and outlet ducts. Although corrosion-resistant alloys appear promising, they are costly and may corrode from chlorides in the flue gas. Consequently, methods of protecting even these materials may need to be developed.

Inlet Ducts

Carbon steel or Cor-Ten steel are used as inlet duct materials at all the installations surveyed except for Milton R. Young, Colstrip, and Hawthorn. The Young and Colstrip ducts have Type 316L stainless steel in the transition section where wet conditions are likely. The Hawthorn units were originally designed for boiler injection of limestone with simultaneous removal of SO_2 and fly ash in a marble bed absorber. The inlet ducts have a gunned refractory concrete lining (Plibrico gunite) to protect the Cor-Ten steel from potential erosion caused by the high particulate loading in the flue gas. Conesville is the only station which reported a problem with inlet ducts. In that case, a short Cor-Ten steel spool piece between the inlet damper and the Carpenter 20 quench duct is corroding and consideration is being given to the use of Uddeholm 904L as a replacement material.



REHEAT IN SCRUBBER VESSEL

Direct Reheat
- Hawthorn 3 & 4
- La Cygne 1*
- Lawrence 4 & 5 (Old)
- Lawrence 4 & 5 (New)
- Mill Creek 3 (Planned)
- Sherburne 1 & 2*

Indirect Reheat
- Windows Creek 8
- Green River (Planned)

Combustion Reheat
- Paddy's Run 6

REHEAT IN OUTLET DUCT

Direct Reheat
- Cane Run 5
- Colstrip 1 & 2*
- Cholla 1 & 2
- Will County 1

Indirect Reheat
- Petersburg 3
- Huntington 1

Combustion Reheat
- Cane Run 4
- Bruce Mansfield 1 & 2* (Inoperable)
- Elrama* (Inoperable)
- Phillips* (Inoperable)

HOT GAS TO OUTLET DUCT

Bypass Reheat
- Tombigbee 2 & 3
- Apache 2 & 3
- Milton Young 2
- Huntington 1
- R. D. Morrow 1 & 2

No Reheat
(Bypass to outlet duct during shutdown of FGD system)
- Duck Creek
- Conesville 5 & 6
- Marion 4

HOT GAS TO STACK

Bypass Reheat
- Winyah 2

No Reheat
(Bypass to stack during shutdown of FGD system)
- Southwest 1
- Green River (Old stack)

*No bypass duct in system.

Figure 3-1. Schematic Diagram Illustrating Location, Type, and Operating Status of Stack Gas Reheat Systems Installed on Utility Station FGD Systems

Table 3-8

DUCTS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Original Materials			Comments
		Inlet Duct	Outlet Duct	Bypass Duct	
Alabama Electric Coop. Tombigbee 2 & 3	9/78 & 6/79	CS[b]	CS lined with CXL-2000[c] to stack and bypass damper	CS	CXL-2000 used several months under full bypass; some blisters but still protective
Arizona Electric Power Coop. Apache 2	2/79	CS	CS lined with CXL-2000	CS	
Apache 3	6/79	CS	CS lined with Flakeline 282-X; contains quench spray	CS	
Arizona Public Service Cholla 1	12/73	CS	CS lined with Flakeline 252	CS	Three relines on module B (Flakeline 252 in 1974, 252 in 1975, and 103 in 1976); Plasite 4030 lining installed on module B outlet duct in 1977; no problems on module A
Cholla 2	5/78	CS	CS lined with Flakeline 103 to bypass and Plasite 4030 to stack	CS; contains quench spray	
Central Illinois Light Duck Creek	7/76	CS	Hastelloy G to breeching; breeching is CS lined with Flakeline 151	Hastelloy G; contains quench spray	Flakeline 151 failed and has not been replaced
Columbus & Southern Ohio Elec. Conesville 5 & 6	1/77 & 4/78	Cor-Ten	Cor-Ten lined with Resista-Flake 1150 to bypass; Cor-Ten lined with Flakeline 151 to stack	Cor-Ten	Flakeline 151 failed on bypass and replaced with Sauereisen No. 54 in 9/76; corrosion of inlet spool so that Uddeholm 904L is being considered as a replacement; outlet spool on Unit 6 will be replaced by Uddeholm 904L because of corrosion
Commonwealth Edison Will County 1	2/72	CS	Cor-Ten lined with Plasite 7122H to unlined Cor-Ten beyond reheater	Cor-Ten near outlet junction	Plasite 7122H deteriorated and Cor-Ten corroding ahead of reheater; holes in inlet duct
Duquesne Light Elrama	10/75	CS	CS lined with Flakeline 103	Not applicable	
Phillips	7/73	CS	CS lined with Flakeline 103 except 316 SS in reheater zone	Not applicable	316 SS reheater zone corroded and repaired with Flakeline 103 in 2/78
Indianapolis Power & Light Petersburg 3	12/77	CS	CS lined with Resista-Flake 1150AR to bypass; then Rigiflake 4850	CS	Rigiflake 4850 coming off breeching in 10/78; due to be relined in 10/79; Resista-Flake 1150AR replaced with same in 4/79 because of wear
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	Cor-Ten lined with Plibrico gunite	Cor-Ten lined with Plibrico gunite	Cor-Ten	
La Cygne 1	6/73	CS	CS	None	Plasite 4005 installed in outlet duct between fan and stack for test purposes
Kansas Power & Light Lawrence 4 & 5 (old)	10/68 & 9/71	CS	CS	Not identified	Severe corrosion problems
Lawrence 4 (new)	1/77	Cor-Ten	Cor-Ten	CS	
Lawrence 5 (new)	4/78	Cor-Ten	Cor-Ten to bypass, then CS to stack	CS	
Kentucky Utilities Green River	9/75	CS	None (stack integral to absorber)	CS; to old stack	
Louisville Gas & Electric Cane Run 4	8/76	CS	CS lined with Carboline to reheater, then CS lined with Pre-Krete G-8 to stack	CS to outlet duct junction	Carboline blistered and replaced with Plasite 4005 in 5/77; minor repairs to Pre-Krete G-8 bypass and breeching in 5/77
Cane Run 5	12/77	CS	CS lined with Flakeline 252 to reheaters, then unlined CS to stack	CS	Lining eroding from soot blowers ahead of reheaters; SS being considered for replacing 3 ft (1 m) zone

Table 3-8 (CONTINUED)

Utility and Plant	Start-Up Date	Original Materials: Inlet Duct	Original Materials: Outlet Duct	Original Materials: Bypass Duct	Comments
Mill Creek 3	7/78	CS	CS lined with Pre-Krete G-8 to stack	CS lined with Pennguard block; contains quench spray	Glass blocks fell out; corrosion repaired with steel plate only in 1/79; spray nozzles also removed from bypass
Paddy's Run 6	4/73	CS	CS	CS	Never run without 50°F (28°C) reheat
Minnkota Power Coop. Milton R. Young 2	5/77	CS to 316 SS transition zone	CS lined with Flakeline 103 except 316 SS reheat bustle	CS	
Montana Power Colstrip 1 & 2	11/75 & 8/76	CS to 316L SS transition zone	CS lined with Rigiflake 4850 except for 316L SS in-line reheater section	None	
Northern States Power Sherburne 1 & 2	5/76 & 4/77	CS	CS	None	
Pennsylvania Power Bruce Mansfield 1 & 2	4/77 & 10/77	CS	CS lined with Rigiflake 4850 to reheater, then Rigiflake 4855	None	
South Carolina Public Service Winyah 2	8/77	Cor-Ten	Cor-Ten lined with Flakeline 103 and Kaocrete to damper, then Plasite and Kaocrete	Not identified; direct to stack	Minor repairs to Kaocrete beyond damper
South Mississippi Elec. Power R.D. Morrow 1	9/78	CS	CS lined with Glass Flake Int. lining to stack	CS	Lining debonded in 1 month; replaced with Dudick lining in 10/78 which failed in 3 months beyond reheater; added quench spray to bypass duct in 10/78
R.D. Morrow 2	6/79	CS	CS lined with Glass Flake Int. lining to stack	CS plus Hastelloy G junction	Relined with Dudick flake glass lining before start-up; not yet inspected in 8/79; plan Hastelloy G outlet ducts for both units
Southern Illinois Power Coop. Marion 4	4/79	CS	CS lined with Resista-Flake to breeching; Inconel 625 breeching	Not identified	
Springfield City Utilities Southwest 1	4/77	CS	CS lined with Rigiflake 4850	CS; direct to stack	Lining failed within 1 month and repaired three times during first year of operation; lining replaced with Plasite 4005 and Plasite 4030 (near absorber outlet) in 10/78; replaced 100 ft^2 (9.3 m^2) in 4/79
Tennessee Valley Authority Widows Creek 8	5/77	Cor-Ten	Cor-Ten	Cor-Ten	Cor-Ten outlet duct is corroding beyond 316L SS reheater duct
Utah Power & Light Huntington 1	5/78	CS	CS lined with Flakeline 103 to bypass reheater, then Pre-Krete G-8	Not identified	

[a]Any materials problems identified are indicated under comments.

[b]Abbreviations used are:
CS = carbon steel
SS = stainless steel

[c]Trade names of linings are identified by generic type in Table 2-2.

Table 3-9

SUMMARY OF OUTLET DUCT MATERIALS PERFORMANCE BY OPERATING CONDITIONS AND COAL TYPE

Operating Conditions	High-Sulfur Coal (Over 1.5%)					Low-Sulfur Coal (Below 1.5 %)				
		Good Service		Failure			Good Service		Failure	
	Station	Material	Years[a]	Material	Years[a]	Station	Material	Years[a]	Material	Years[a]
Wet Gas	Duck Creek	Hastelloy G	3			Milton R. Young 2	Flakeline 103	2		
	Conesville 5 & 6	Resista-Flake 1150	2			Colstrip 1 & 2	Rigiflake 4850	3-1/2		
	Elrama	Flakeline 103	3-1/2			Apache 2	CXL-2000	New		
	Phillips	Flakeline 103	6			Apache 3	Flakeline 282-X	New		
	Cane Run 4	Plasite 4005	2	Carboline	1/2	Cholla 1 (module A)	Flakeline 252	5-1/2		
	Mill Creek 3	Pre-Krete G-8	1			Cholla 1 (module B)	Plasite 4030	2	Flakeline 252 & 103	1
	Bruce Mansfield 1 & 2	Rigiflake 4850 & 4855	3-1/2			Huntington 1	Flakeline 103	1		
	R. D. Morrow 1 & 2	Dudick flake glass	1/2	Glass Flake Int.	1/4	Will County 1	Plasite 7122H (before reheaters)	7	Plasite 7122H (near reheaters)	<7
	Marion 4	Resista-Flake	New							
	Southwest 1	Plasite 4005 & 4030	1/2	Rigiflake 4850	1/2	Cholla 2	Flakeline 103	1		
	Tombigbee 2 & 3	CXL-2000	1/2							
	Petersburg 3	Resista-Flake 1150AR	1							
	Cane Run 5	Flakeline 252	1-1/2							
Wet Gas and Hot Gas	Duck Creek 1	Hastelloy G	3	Flakeline 151	<1					
	Conesville 5 & 6	Sauereisen No. 54	3	Flakeline 151	<1					
	Mill Creek 3	--		Pennguard mortar	<1					
	Marion 4	Inconel 625	New							
	R. D. Morrow 1			Flake glass	<1/4					
	R. D. Morrow 1			Dudick flake glass	<1/4					
	R. D. Morrow 2	Dudick flake glass[b]	New							
Reheated Gas	Paddy's Run 6	Carbon steel	6			Cholla 1 (module A)	Flakeline 252	5-1/2		
	Cane Run 4	Pre-Krete G-8	3[c]			Cholla 1 (module B)	Plasite 4030	2	Flakeline 252 & 103	1
	Petersburg 3	Resista-Flake 1150AR	1			Cholla 2	Flakeline 103	1		
	Hawthorn 3 & 4	Cor-Ten & gunite	6-1/2			Will County 1	Cor-Ten	7		
	La Cygne 1	Carbon steel	6-1/2			Lawrence 4 (new)	Cor-Ten	2		
	Cane Run 5	Carbon steel	1-1/2			Lawrence 5 (new)	Cor-Ten	1		
	Widows Creek 8	Cor-Ten	2			Colstrip 1 & 2	Rigiflake 4850	3-1/2		
						Sherburne 1 & 2	Carbon steel	3		
						Winyah 2	Plasite & Kaocrete	2		
Reheated Gas and Hot Gas	Hawthorn 3 & 4	Cor-Ten & gunite	6-1/2			Apache 2	CXL-2000	1/2		
	Cane Run 4	Pre-Krete G-8	3			Apache 3	Flakeline 282-X	New		
	Cane Run 5	Carbon steel	1-1/2			Will County 1	Cor-Ten	7		
	Paddy's Run 6	Carbon steel	6			Milton R. Young 2	Flakeline 103	2		
	Widows Creek 8	Cor-Ten	2			Huntington 1	Pre-Krete G-8	1		
	Petersburg 3			Rigiflake 4850	<1	Cholla 1	Plasite 4030	2	Flakeline 252 & 103	1
	Tombigbee 2 & 3	CXL-2000	1/2			Cholla 2	Plasite 4030	2		
	Lawrence 4 (old) & 5 (old)			Carbon steel	<6	Lawrence 4 (new)	Cor-Ten	2		
						Lawrence 5 (new)	Carbon steel	1		

[a]As of mid-1979.

[b]Not yet inspected.

[c]Includes 1/2 year operation without reheat (added June, 1977).

Outlet Ducts

Outlet duct materials listed in Table 3-8 range from unlined carbon steel in reheated zones of Sherburne and the breeching of new Lawrence 5, to the use of Hastelloy G at Duck Creek and Inconel 625 at Marion. Environmental differences related to the location and use of reheaters, and the sulfur oxides concentration in the flue gas exiting the absorber are factors which affect the use of different materials. At most stations, the outlet ducts are exposed to different flue gas conditions, i.e., before and after the reheater and/or before and after the bypass junction. Outlet duct data from Table 3-8 have been summarized in Table 3-9 using categories that reflect the probable duct environment.

Wet Gas. Units which have wet outlet duct sections predominantly use organic linings to protect the carbon (or Cor-Ten) steel structure. Exceptions are the use of Hastelloy G at Duck Creek and Pre-Krete G-8 at Mill Creek (where reheaters are to be added). There have been some lining failures, including an unidentified epoxy at Cane Run 4 which was replaced with an inert flake-filled vinyl ester (Plasite 4005), a glass flake-filled polyester at R. D. Morrow which was replaced with the same type of lining (Protecto-Flake 500) but from a different manufacturer, and a glass-flake filled polyester (Rigiflake 4850) at Southwest which was replaced by inert flake-filled vinyl esters (Plasite 4005 and 4030). However, for the most part the organics are providing several years of service both for high sulfur and low sulfur coals. Some representative operating lives thus far (operation is continuing) are 6-1/2 years for a glass flake-filled polyester (Flakeline 103) at Phillips, 2-1/2 years for an inert flake-filled vinyl ester (Plasite 4005) at Cane Run 4, and 8 years for a mat-reinforced epoxy phenolic (Plasite 7122H) at Will County. The use of fluoroelastomer linings at Apache and Tombigbee is too recent to judge their performance.

Wet Gas and Hot Gas. Units which have duct sections which handle both wet gas and hot gas have experienced failure of organic linings. At Duck Creek and Conesville, the mica flake-filled polyester linings (Flakeline 151) in the stack breechings both failed under bypass conditions before scrubber startup. The lining was replaced with Hastelloy G at Duck Creek and with a chemically bonded concrete lining (Sauereisen No. 54) at Conesville. The replacements have performed satisfactorily thus far for 3-1/2 years in both cases. At R. D. Morrow, bypass reheat is not used until above 62 percent boiler load, which means the ducts beyond the reheater run wet (or reheated at high loads) unless the FGD system is bypassed. This environmental difference is probably a major reason for rapid failure of the glass flake-filled polyester linings at Morrow. Consideration is being given to installing Hastelloy G, or similar alloy, from the absorber to the stack.

Reheated Gas. Stations which have outlet duct sections exposed only to reheated gas have had a good record of materials performance, as no problems were reported except in the special case of module B at Cholla 1. This case represents an extreme environment of flue gas which is not treated for SO_2 removal (limestone slurry is not added), and water with a high chloride content. Module B is operated for particulate removal only because there is no electrostatic precipitator and the SO_2 emission regulation can be met with one module on-line. The same mica flake-filled polyester lining (Flakeline 252) on module A where SO_2 is scrubbed has not been a problem. In as much as unlined carbon and Cor-Ten steels are giving service lives of 6-1/2 to 8 years thus far for both high sulfur and low sulfur coal units (La Cygne and Will County), it is quite likely that organic or inorganic linings may not be required for this type of environment except as a precautionary measure.

Reheated Gas and Hot Gas. Outlet duct sections which handle both reheated gas and hot gas have less problems than those which handle wet gas and hot gas, but a few problems have occurred. Severe corrosion problems were experienced with the carbon steel outlet ducts of the old Lawrence 4 and 5 units which at one time burned high sulfur Kansas coal. However, carbon steel and Cor-Ten steel have been used successfully for more than 7 years thus far at Paddy's Run and Will County, respectively. Differences in performance may be attributable to the temperature rise provided by the reheat system and the sulfur oxides concentration in the flue gas exiting the absorber. Therefore, it is difficult to determine if linings are needed for this type of environment.

The failure of a glass flake-filled polyester lining (Rigiflake 4850) at Petersburg may be related to a large amount of bypass operation during the start-up of this unit. Other organic linings in use for this service with no problems reported include fluoroelastomers for 1-1/2 years at Tombigbee (CXL-2000), for 1 year at Apache 2 (CXL-2000), and recently installed at Apache 3 (Flakeline 282-X), a glass flake-filled polyester for 2-1/2 years at Milton R. Young (Flakeline 103), and an inert flakefilled vinyl ester for 1-1/2 years at Cholla 2 (Plasite 4030). Inorganic linings (hydraulic bonded concretes) are used successfully thus far for this service for 7 years at Hawthorn (gunite), for 3-1/2 years at Cane Run 4 (Pre-Krete G-8), and for 1-1/2 years at Huntington (Pre-Krete G-8).

Bypass Ducts

Bypass ducts are used to carry all of the flue gas during a shut down of the FGD system and/or part of the flue gas for bypass reheat. These ducts are generally unlined carbon or Cor-Ten steel at least to the damper to the outlet duct. The bypass duct at Duck Creek is Hastelloy G, as is a 7 foot (2 m) section of the bypass duct ahead of the reheat section at R. D. Morrow 2. At Morrow 1, this 7 foot (2 m) section is carbon steel with a glass flake/polyester lining (Protecto-Flake 500). The only problem reported for bypass duct materials is at Mill Creek where the emergency bypass duct was lined with foam glass blocks (mortar type unknown) and had a water spray section to quench the gas for stack lining protection during bypass operation. The blocks fell out after several months of operation and the carbon steel duct became badly corroded. The spray nozzles were removed and the duct was patched with carbon steel plate. No further problems were reported. The other installations with emergency quench sprays are Duck Creek, Cholla 2, R. D. Morrow 1, and Apache 3, although in the latter case the nozzles are located in the outlet duct rather than the bypass duct.

EXPANSION JOINTS

Expansion joints are installed in FGD systems to provide capacity for deflection so as to relieve strains caused by thermal expansion. They are usually installed in the inlet and outlet ductwork to provide axial flexibility. Thus, the joints are exposed to the same conditions as the ducts in which they are installed. Expansion joints are generally U-shaped and constructed of an elastomer with fabric (fiberglass or asbestos) reinforcement. However, some metal bellows type expansion joints are also used. The biggest problem with wet side (downstream from the absorber) expansion joints has been what metal to use for attachment purposes, rather than with the fabric itself. The kind of expansion joint selected is dependent upon temperature to be encountered. Suppliers suggest the following guidelines for materials to be used at the temperatures indicated.

- At 250°F (121°C) or below, fabric-reinforced neoprene
- At 300°F (149°C) or below, fabric-reinforced chlorobutyl rubber
- At 400°F (204°C) or below, fabric-reinforced fluoroelastomer such as Viton®
- Above 400°F (204°C), layered asbestos.

Metal expansion joints have been used successfully in some cases, especially under dry conditions. However, even stainless steels can give problems if condensate is high in acid concentration, and/or contains high chlorides. Information on materials of construction for expansion joints is summarized in Table 3-10.

Several FGD installations have replaced metal expansion joints downstream (wet side) from the absorber with elastomer joints because of corrosion problems. These include Cholla 1 (Type 316L stainless steel to fluoroelastomer), Phillips (Type 405 stainless steel to chlorobutyl rubber), Hawthorn (Cor-Ten steel to fluoroelastomer), and the original systems at Lawrence 4 and 5 (steel to butyl rubber). At Cholla, the metal failed because of condensate puddles that formed in the bottom of the joints. The metal joints in the wet gas outlet side at Phillips failed in about 6 months and were replaced with elastomer joints. Cracks developed in the chlorobutyl rubber replacement joints at the wet fan inlet and discharge areas so that these joints were replaced with the same material after 23,000 to 24,000 hours of service. Other installations that have metal expansion joints are Duck Creek (Carpenter 20 on hot inlet side and Hastelloy G on wet outlet side) and R. D. Morrow (Cor-Ten steel on inlet side).

At Sherburne, chlorobutyl rubber inlet expansion joints failed during the first year and were replaced with fluoroelastomer joints; however, the chlorobutyl rubber has performed satisfactorily on the outlet side. Rubber expansion joints also failed at La Cygne because the temperature rating was exceeded; they were replaced with fluoroelastomer joints. The original joints had carbon steel supports which corroded rapidly. The new joints were changed from internal to external bolting. At Green River, elastomer expansion joints have been replaced with stainless steel, and at Southwest, elastomer expansion joints at the fan outlet may be replaced with Inconel 625 because of problems. Other installations reporting problems with elastomer expansion joints are Cane Run 4, Colstrip, and Tombigbee. At the first site, the rubber joints were replaced with the same material in 1977 because of evidence of leakage. At the second site, there is wear of the fluoroelastomer inlet joints and replacement with the same material is planned. At the last site, one fluoroelastomer expansion joint in the bypass duct failed and was patched unsuccessfully so that it will be replaced with the same material.

Table 3-10

EXPANSION JOINTS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Original Materials	Comments
Alabama Electric Coop. Tombigbee 2 & 3	9/78 & 6/79	Viton®/asbestos	One expansion joint in bypass duct failed and patched unsuccessfully
Arizona Electric Power Coop. Apache 2 & 3	2/79 & 6/79	Viton®/asbestos	
Arizona Public Service Cholla 1	12/73	316L SS[b]	Condensate puddles in bottoms of joints caused failures; successfully replaced with canvas-reinforced Viton®
Cholla 2	5/78	Viton®/asbestos	
Central Illinois Light Duck Creek	7/76	Carpenter 20 on inlet side and Hastelloy G on outlet side	Internal cover plates were added to prevent ash buildup
Columbus & Southern Ohio Elec. Conesville 5 & 6	1/77 & 4/78	Teflon®/asbestos	
Commonwealth Edison Will County 1	2/72	Asbestos-type construction	
Duquesne Light Elrama	10/75	Butyl rubber/asbestos on outlet side	
Phillips	7/73	405 SS on outlet side	Joints failed from corrosion in about 6 months; replaced with butyl rubber/asbestos; cracks developed in rubber at fan inlet and discharge so they were replaced after 24,000 hours of service
Indianapolis Power & Light Petersburg 3	12/77	Rubber	
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	Cor-Ten steel	Joints corroded and are to be replaced with Viton®/asbestos
La Cygne 1	6/73	Rubber with carbon steel supports	Joints failed because temperature rating was exceeded; replaced with Viton®/glass fiber; supports corroded rapidly; changed from internal to external bolting
Kansas Power & Light Lawrence 4 & 5 (old)	10/68 & 9/71	Metal	Joints failed and replaced with butyl rubber
Lawrence 4 & 5 (new)	1/77 & 4/78	Viton®/asbestos and butyl rubber/asbestos	
Kentucky Utilities Green River	9/75	Viton®/fabric	Joints tore loose and were replaced with SS bellows
Louisville Gas & Electric Cane Run 4	8/76	Rubber	Replaced in 1977 because of evidence of leakage
Cane Run 5	12/77	Rubber	
Mill Creek 3	7/78	Not identified	
Paddy's Run 6	4/73	Rubber	
Minnkota Power Coop. Milton R. Young 2	5/77	Viton®/asbestos on inlet side and chlorobutyl rubber/asbestos on outlet side	
Montana Power Colstrip 1 & 2	11/75 & 8/76	Viton®/asbestos	Wear of inlet joint; will be replaced with same material

Table 3-10 (CONTINUED)

Utility and Plant	Start-Up Date	Original Materials	Comments
Northern States Power Sherburne 1 & 2	5/76 & 4/77	Chlorobutyl rubber	Joints on inlet side failed in first year; replaced with Viton®; chlorobutyl rubber is satisfactory on outlet side
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	Neoprene/asbestos	
South Carolina Public Service Winyah 2	8/77	Rubber	
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	Cor-Ten steel on inlet side and rubber/fabric with 316L SS shields on outlet side	Shields are badly corroded and will be replaced with Hastelloy G
Southern Illinois Power Coop. Marion 4	4/79	Butyl rubber	
Springfield City Utilities Southwest 1	4/77	Viton® at fan outlet, Cor-Ten steel in bypass ducts, and asbestos-filled elastomer on outlet side	Viton® joints may be replaced with Inconel 625 because of the many problems experienced
Tennessee Valley Authority Widows Creek 8	5/77	Not identified	
Utah Power & Light Huntington 1	5/78	Rubber/fabric	

[a]Any materials problems identified are indicated under comments.

[b]SS = stainless steel.

DAMPERS

Dampers are used in the ductwork of FGD systems for isolation of sections or components from the flue gas and for control of the flue gas flow rate. Three types of dampers are in use, namely louver, guillotine, and butterfly. Louver dampers have a higher leakage rate than guillotine dampers, and therefore the latter offer an advantage with particulate-laden flue gas because of the more positive sealing action. On the other hand, guillotine dampers in the open position will leak to the atmosphere across the blade passage unless the blade is enclosed in a bonnet. This problem can be avoided by the use of butterfly dampers because the blade is located inside the duct even in the open position. Zero leakage can be achieved only by using double dampers with a higher pressure air barrier between them. However, even with this design, dampers can still leak in a dirty environment. Because of the leakage problem, it may be necessary to shut down the boiler to maintain the FGD system.

Mechanical problems with dampers, caused by deposition of solids from the flue gas, have outweighed any materials problems. However, corrosion and erosion do occur. Dampers are utilized in three locations: on the inlet duct to the scrubber, the outlet duct from the scrubber, and the bypass duct which goes directly from the air preheater or dry particulate collector to the stack. Some installations have no bypass duct, and all of the flue gas goes through the scrubber system. Descriptions of the damper materials in the FGD systems included in this study are given in Table 3-11.

Inlet Dampers

The inlet dampers used on the lime/limestone systems are about evenly divided between guillotine and louver type, with a few butterfly dampers in use. Because the inlet dampers are subjected to the hot, relatively dry flue gases ahead of the scrubber, it is possible to utilize unlined carbon steel in this location. This material is used at several of the sites, particularly those where low sulfur coal is burned and the sulfur oxide concentrations are relatively low. However, the damper seals usually are an alloy such as Type 316L stainless steel, Hastelloy G, or Inconel 625. The only plants citing corrosion of carbon steel inlet dampers were Phillips and the original installations at Lawrence, both of which were burning high sulfur coal at the time. The corrosion was probably caused by acid condensation because of the high concentration of sulfur oxides. At Phillips, the inlet dampers were clad with Type 316L stainless steel, and the new installations at Lawrence use Cor-Ten steel inlet dampers and burn low sulfur coal.

Table 3-11

DAMPERS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Inlet Dampers	Outlet Dampers	Bypass Dampers
Alabama Electric Coop.				
Tombigbee 2 & 3	9/78 & 6/79	Guillotine (Mosser), CS[b] with Incoloy 625 cladding and 316SS seals for isolation Louver, CS for control Corrosion of seal air blowers	Guillotine, CS with Incoloy 825 cladding and In 625 seals	Louver, CS
Arizona Electric Power Coop.				
Apache 2 & 3	2/79 & 6/79	Louver, CS for control	Guillotine, CS with 317L SS cladding on wet side and In 625 seals	Louver, CS with In 625 cladding on wet side
Arizona Public Service				
Cholla 1	12/73	Guillotine, 316L SS	Same as inlet	Same as inlet
Cholla 2	5/78	Guillotine, double blade, CS with 317L SS cladding and In 625 seals	Louver, 317L SS with In 625 seals	Inlet, same as inlet damper Outlet, same as outlet damper
Central Illinois Light				
Duck Creek	7/76	Guillotine, CS - one module was changed from a louver type	Guillotine, Hastelloy G	Louver, Hastelloy G - some leakage problems.
Columbus & Southern Ohio Elec.				
Conesville 5 & 6	1/77 & 4/78	Guillotine, CS with 316L SS seals - corroded seals replaced with In 625	Guillotine, In 625	Guillotine, In 625 for isolation Louver, In 625 for control
Commonwealth Edison				
Will County 1	2/72	Louver, Cor-Ten steel	Louver, CS	Louver, CS
Duquesne Light				
Elrama	10/75	Louver, 316L SS for fan inlet Butterfly, CS with 316L SS cladding for isolation	Butterfly, 316L SS	None
Phillips	7/73	Louver, CS clad with 316L SS for fan inlet - corroded; Flakeline 103 and Coroline 505 linings used Butterfly, CS for isolation - corroded; covered with 316L SS sheet	Butterfly, 316L SS	None
Indianapolis Power & Light				
Petersburg 3	12/77	Guillotine, CS with Carpenter 20 seals	Same as inlet	Same as inlet
Kansas City Power & Light				
Hawthorn 3 & 4	11/72 & 8/72	Louver, Cor-Ten steel	Louver, Cor-Ten steel	Guillotine, Cor-Ten steel
La Cygne 1	6/73	Louver, CS	Louver, CS - replacing with 316L SS	None
Kansas Power & Light				
Lawrence 4 & 5 (old)	10/68 & 9/71	Louver, CS - corroded	Louver, CS - corroded	Louver, CS
Lawrence 4 & 5 (new)	1/77 & 4/78	Louver, Cor-Ten steel	Louver, Cor-Ten steel	Louver, Cor-Ten steel; one guillotine on Unit 4
Kentucky Utilities				
Green River	9/75	Guillotine, CS	Guillotine, CS	Guillotine, CS

Table 3-11 (CONTINUED)

Utility and Plant	Start-Up Date	Inlet Dampers	Outlet Dampers	Bypass Dampers
Louisville Gas & Electric Cane Run 4	8/76	Guillotine, CS with 316L SS seals	Same as inlet	Same as inlet
Cane Run 5	12/77	Louver, CS frame with 316L SS blades	Same as inlet	Same as inlet
Mill Creek 3	7/78	Not identified	Not identified	Not identified
Paddy's Run 6	4/73	Louver, CS	Same as inlet	Same as inlet
Minnokota Power Coop. Milton R. Young 2	5/77	Guillottine, CS	Guillotine, 316L SS	Inlet, CS. Outlet, butterfly, 316L SS
Montana Power Colstrip 1 & 2	11/75 & 8/76	Butterfly, CS	Guillotine (Mosser), 316L SS blade & angle	None
Northern States Power Sherburne 1 & 2	5/76 & 4/77	Butterfly, CS (soot blown)	Butterfly, CS	None
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	Butterfly, 316L SS	Louver, 316L SS	None
South Carolina Public Service Winyah 2	8/77	Guillotine, Cor-Ten steel	Louver, organic coating (probably Ceilcote)	Same as outlet
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	Louver, CS	Louver, high alloy and organic lining (Dudick) with Hastelloy G seal strips	Same as outlet
Southern Illinois Power Coop. Marion 4	4/79	Guillotine, dual blade, CS	Guillotine, dual blade, In 625 - seal failure on stack side.	Louver, double, In 625 on stack side and CS on scrubber side
Sprinfield City Utilities Southwest 1	4/77	Louver, double, CS with In 625 seals	Louver, double, 316L SS - corroded in 3 months; now Uddeholm 904L with In 625 seals	Louver, double, CS with In 625 seals
Tennessee Valley Authority Widows Creek 8	5/77	Guillotine, Cor-Ten steel blades with 316L SS seals - seals replaced with In 625	Same as inlet	Same as inlet
Utah Power & Light Huntington 1	5/78	Guillotine, dual blade, CS with Hastelloy seal	Guillotine, 316L SS, followed by louver, 316L SS; Hastelloy seals	Butterfly, 316L SS with Hastelloy seal

[a]Any materials problems identified are indicated under item description.

[b]Abbreviations used are:
CS = carbon steel
SS = stainless steel
In = Inconel

The Type 316L stainless steel damper seals used in conjunction with carbon or Cor-Ten steel suffered corrosion damage at Conesville and Widows Creek as a result of high chloride concentrations and the seals were successfully replaced with Inconel 625. In spite of the hot, relatively dry conditions at the inlet, most of the systems have inlet dampers constructed of Cor-Ten steel or clad with stainless steel in order to avoid possible corrosion. Type 316L stainless steel inlet dampers have operated at Cholla 1 for 6 years and at Bruce Mansfield for 3-1/2 years without any problems thus far.

Outlet Dampers

The dampers on the scrubber outlet are subject to the wet flue gas and for this reason greater use has been made of stainless steels, either as a cladding or for the entire construction. Duck Creek has Hastelloy G for the outlet damper, and Conesville uses Inconel 625. Glass flake-filled polyester linings on carbon steel or a high alloy are utilized at Winyah and R. D. Morrow, respectively. The only reports of corrosion were the original carbon steel dampers at Lawrence which were replaced with Cor-Ten steel, and at La Cygne, where Type 316L stainless steel was the replacement. Type 316L stainless steel at Southwest corroded badly in 3 months as a result of high chloride concentrations and was replaced with a Uddeholm 904L frame, Inconel 625 seals, and Hastelloy C fasteners. The replacement is satisfactory after more than one year of service.

Bypass Dampers

Where bypass dampers are used, they are usually constructed of the same materials as the outlet damper because they can be exposed to the wet flue gas. An exception is at Apache where Inconel 625 cladding is used on the wet side of the bypass damper, as compared to Type 317L stainless steel on the outlet damper. No serious corrosion problems were reported for bypass dampers, as the chief difficulties have been mechanical operation and clogging of the seals.

STACKS

The flue gas from an FGD system exits to the atmosphere through a chimney or stack. The stack consists of an outer shell constructed of concrete or carbon steel and one or more flues constructed of brick or metal which carry the flue gas. The interior surface of the flue is subjected to the flue gas conditions and therefore provisions must be made for protection against corrosion. These provisions include the use of corrosion-resistant materials or linings and/or the control of environmental conditions to prevent condensation. In some cases, a steel stack is used to carry the flue gas directly without a flue so that the interior surface of the stack must be protected. The stack is usually connected to the outlet duct by a short section of duct called a breeching. However, in at least one case (Green River) the stack is connected directly to the top of the absorber.

Information collected on stack lining materials is compiled in Table 3-12. Information on breechings is covered in a previous section on outlet ducts. All units with bypass capability except Winyah, Southwest, and Green River have a bypass-scrubbed gas junction in the duct leading to the stack. The latter units bypass directly to the stack (the original stack in the case of Green River which is separate from the absorber stack).

The performance of a stack lining depends on whether the scrubbed gas is delivered to the stack wet or reheated, and whether or not the stack is also used for hot bypassed gas. These factors appear to have a stronger effect on the performance of lining materials than differences in fuel sulfur, application techniques (e.g., surface preparation or priming), operating procedures (e.g., thermal shock), design aspects (e.g., annulus pressurization), and other factors which can affect performance. Information on fuel sulfur was collected and used in an analysis of performance, but it is not fuel sulfur, nor SO_2, but SO_3 in the stack gas which forms the sulfuric acid (or hydrated sulfate salts) which degrades materials. Although information was collected on SO_2 in the exhaust gas, no information was available on SO_3 content, so the sulfur content of the fuel was used to distinguish materials performance by operating conditions. The stack lining results from Table 3-12 are summarized in Table 3-13 according to the operating conditions to which the stack is exposed. Although R. D. Morrow has operable bypass reheaters, they are not used at partial loads. Consequently, this stack is classified in the "wet and hot" category in Table 3-13 rather than in the "reheated and hot" category.

Acid-resistant brick linings have exhibited good performance regardless of operating conditions. However, in spite of their successful background they have two limitations: (1) acid penetration of the brick, mortar, or brick-mortar interface may occur under wet conditions, and (2) they may not be suitable linings in earthquake-prone areas. It remains to be seen whether pressurization of the stack annulus can solve the penetration problem under wet conditions.

Table 3-12

STACKS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Stack Height, ft (m)	Original Materials: Shell	Flue	Lining	Comments
Alabama Electric Coop.						
Tombigbee 2	9/78	400 (122)	Concrete	ARB[b]	None	Annulus is pressurized
Tombigbee 3	6/79	400 (122)	Common with Unit 2	ARB	None	Annulus is pressurized
Arizona Electric Power Coop.						
Apache 2	2/79	400 (122)	Concrete	CS	CXL-2000[c]	
Apache 3	6/79	400 (122)	Common with Unit 2	CS	Flakeline 282-X	
Arizona Public Service						
Cholla 1	12/73	250 (76)	Concrete	ARB and mortar on corbels	None	
Cholla 2	5/78	550 (168)	Concrete	CS	Plasite 4030	Stack also has unlined CS flue for Unit 3 which does not have FGD system
Central Illinois Light						
Duck Creek	7/76	500 (152)	Concrete	CS	Flakeline 151	Lining blistered in lower part on bypass in spite of 250°F (121°C) quench; repaired with same material; Inconel 625 being considered for transition section and ash hopper
Columbus & Southern Ohio Elec.						
Conesville 5	1/77	800 (244)	Concrete	Cor-Ten	Flakeline 151	Lining failed; steel flue removed and replaced with ARB and Sauereisen No. 65 mortar in 3/78; annulus is pressurized to 1/2 in. H_2O (125 Pa), but reinforcing bands are failing
Conesville 6	4/78	800 (244)	Common with Unit 5	Common with Unit 5		
Commonwealth Edison						
Will County 1	2/72	350 (107) (2 stacks)	CS	ARB and acid-resistant mortar	None	Stacks were built in 1954
Duquesne Light						
Elrama	10/75	400 (122)	Concrete	LARB and Sauereisen No. 65 mortar	None	Annulus is not pressurized; reinforcing bands bands are corroding
Phillips	7/73	340 (104)	Concrete	LARB and Sauereisen No. 65 mortar	None	Annulus is not pressurized; reinforcing bands are corroding; mortar repointed but still weeps
Indianapolis Power & Light						
Petersburg 3	12/77	613 (187)	Concrete	CS	Rigiflake 4850	Base coat of lining was trowel applied and top coat was spray applied; top coat blistered on bypass; lining replaced with two trowel coats coats of Rigiflake 4850 in 4/79
Kansas City Power & Light						
Hawthorn 3	11/72	200 (61)	CS	None	Gunite	Lining installed in 1953 when stack was built
Hawthorn 4	8/72	200 (61)	Common with Unit 3			
La Cygne 1	6/73	700 (213)	Concrete	CS	Rigiflake lining	Lining failed in 6 months; relined with Plasite 4005 in 1975; lining failed and relined with Plasite 4005 in 1976; lining failed again and relined with Plasite 4005 in 1977; some debonding is occurring

Table 3-12 (CONTINUED)

Utility and Plant	Start-Up Date	Stack Height, ft (m)	Original Materials Shell	Flue	Lining	Comments
Kansas Power & Light						
Lawrence 4 (old)	10/68	180 (55)	CS	None	Haydite/ Lumnite gunite	Lining installed in 1959
Lawrence 4 (new)	1/77	200 (61)	Cor-Ten	None	Sauereisen No. 33	
Lawrence 5 (old)	9/71	350 (107)	CS	None	Haydite/ Lumnite gunite	
Lawrence 5 (new)	4/78	350 (107)	CS	None	Haydite/ Lumnite gunite	Original stack and lining on old Unit 5, spalling in top 100 feet (30 m)
Kentucky Utilities						
Green River	9/75	78 (24) above absorber and 165 (50) above grade	CS	None	Carboline lining	Lining failed after 13,000 hours causing corrosion of the stack; stack repaired and relined with Pre-Krete G-8 which is satisfactory after 8,000 hours
Louisville Gas & Electric						
Cane Run 4	8/76	250 (76)	Concrete	ARB on corbels	None	Mortar failed (type unknown) and concrete attacked without reheat; bricks replaced with Pre-Krete G-8 and reheater installed in 6/77
Cane Run 5	12/77	250 (76)	Concrete	ARB on corbels	Pre-Krete G-8	Bricks removed from top 50 feet (15 m) and lining installed in entire stack in 9/77 before FGD system startup
Mill Creek 3	7/78	600 (183)	Concrete	CS	Flakeline 151	Lining is deteriorating and will not be replaced
Paddy's Run 6	4/73	250 (76)	Corcrete	ARB on corbels	Pre-Krete G-8	Lining installed in 10/72 before FGD system start-up; repaired with HES gunite and Pre-Krete G-8 in 4/75, HES gunite replaced in 5/76 due to poor application
Minnkota Power Coop.						
Milton R. Young 2	5/77	550 (168)	Concrete	Cor-Ten	None	Flue is insulated
Montana Power						
Colstrip 1	11/75	503 (153)	Concrete	CS	Flakeline 151	
Colstrip 2	8/76	503 (153)	Concrete	CS	Flakeline 151	
Northern States Power						
Sherburne 1	5/76	650 (198)	Concrete	Cor-Ten	None	
Sherburne 2	4/77	650 (198)	Common with Unit 1	Common with Unit 1		
Pennsylvania Power						
Bruce Mansfield 1	4/76	950 (290)	Concrete	CS (2 flues)	Rigiflake 4855 in lower 50 ft and Rigiflake 489 in rest	Lining deteriorated and 1A flue was badly corroded; patched with steel plates and relined with Rigiflake 4850 in 8/77, began blistering in 6/79; 1B flue relined with CXL-2000 in 3/78
Bruce Mansfield 2	10/77	950 (290)	Common with Unit 1	CS (2 flues)	Rigiflake 4855 in lower 50 feet and Rigiflake 489 in rest	Lining deteriorated, 2A and 2B flues relined with CXL-2000 in 3/79 and 8/78, respectively
South Carolina Public Service						
Winyah 2	8/77	400 (122)	Concrete	Cor-Ten	Rigiflake 480-4800	Some lining failures below wet gas inlet
South Mississippi Electric Power						
R. D. Morrow 1	9/78	400 (122)	Concrete	ARB and Sauereisen No. 65 mortar	None	
R. D. Morrow 2	6/79	400 (122)	Common with Unit 1	ARB and Sauereisen No. 65 mortar	None	

Table 3-12 (CONTINUED)

Utility and Plant	Start-Up Date	Stack Height, ft (m)	Original Materials: Shell	Flue	Lining	Comments
Southern Illinois Power Coop. Marion 4	4/79	400 (122)	Concrete	HARB and Corlok B mortar	None	Original steel flue design changed to ARB
Springfield City Utilities Southwest 1	4/77	389 (119)	Concrete	ARB and Corlok B mortar	Stackfas in top and on reinforcing bands	Annulus is not pressurized; problems in top 10 feet (3 m)
Tennessee Valley Authority Widows Creek 8	5/77	500 (152)	Concrete	HARB and mortar, upper portion on corbels; cast iron reinforcing bands	None	Annulus is not pressurized
Utah Power & Light Huntington 1	5/78	600 (183)	Concrete	HARB and Corlok B mortar	None	Annulus can be pressurized

[a]Any materials problems identified are indicated under comments.

[b]Abbreviations used are:
ARB = acid-resistant brick
CS = carbon steel
HARB = Type H acid-resistant brick
LARB = Type L acid-resistant brick.

[c]Trade names of linings are identified by generic type in Table 2-2.

Table 3-13

SUMMARY OF STACK LINING MATERIALS PERFORMANCE BY OPERATING CONDITIONS AND COAL TYPE

	High-Sulfur Coal (Over 1.5%)					Low-Sulfur Coal (Below 1.5%)				
		Good Service		Failure			Good Service		Failure	
Operating Conditions	Station	Material	Years[a]	Material	Years[a]	Station	Material	Years[a]	Material	Years[a]
Wet Gas (includes stations with inoperable reheaters)	Elrama	LARB[b] & Sauereisen No. 65	4	Reinforcing bands	2-1/2					
	Phillips	LARB & Sauereisen No. 65	6	Reinforcing bands	2-1/2					
	Green River	Pre-Krete G-8	1	Carboline	2					
	Bruce Mansfield 1 & 2	CXL-2000	1	Rigiflake (2 types)	1					
Wet Gas and Quenched Hot Gas	Duck Creek	Flakeline 151 (top)	3	Flakeline 151 (bottom)	<3					
Wet Gas and Hot Gas	Conesville 5 & 6	ARB & Sauereisen No. 65	1-1/2	Flakeline 151	1					
	Cane Run 4			Old mortar	1					
	Mill Creek 3			Flakeline 151	1					
	Marion 4	HARB & Corlok B	New							
	Southwest 1	ARB & Corlok B	2							
	R. D. Morrow 1	ARB & Sauereisen No. 65	1/2							
	R. D. Morrow 2	ARB & Sauereisen No. 65	New							
Reheated Gas	La Cygne 1	Plasite 4005	2	Rigiflake & Plasite 4005	1-2	Colstrip 1	Flakeline 103	3-1/2		
						Colstrip 2	Flakeline 103	3		
						Sherburne 1 & 2	Cor-Ten	3		
Reheated Gas and Hot Gas	Petersburg 3			Rigiflake 4850	1-1/2	Cholla 1	ARB	5-1/2		
	Hawthorn 3 & 4	Gunite	7			Cholla 2	Plasite 4030	1		
	Cane Run 4	Pre-Krete G-8	2			Will County	ARB	7		
	Cane Run 5	ARB & Pre-Krete G-8	1-1/2			Lawrence 4 (new)	Sauereisen No. 33	2		
	Paddy's Run 6	ARB & Pre-Krete G-8	6			Lawrence 5 (new)	Haydite/Lumnite	1		
	Widows Creek 8	HARB & Corlok B mortar	2			Milton R. Young 2	Cor-Ten	2		
	Lawrence 4 (old)	Haydite/Lumnite	8			Winyah 2	Rigiflake 480/4800[c]	1		
	Lawrence 5 (old)	Haydite/Lumnite	8			Huntington 1	HARB & Corlok B	5		
	Tombigbee 2 & 3	ARB	1/2			Apache 2	CXL-2000	1/2		
	Pleasants 1[d]			Plasite 4005	<1/2	Apache 3	Flakeline 282-X	New		

[a]As of mid-1979.

[b]Abbreviations used are:
ARB = acid-resistant brick
HARB = Type H acid-resistant brick
LARB = Type L acid-resistant brick.

[c]Minor repairs.

[d]Formally not within scope of study; lining failed on bypass before FGD system start-up.

Hydraulic cement bonded concretes (Pre-Krete G-8 and Haydite/Lumnite mixes) have been successfully used under dry conditions for up to 8 years with high sulfur fuel, and have given over one year of service under wet conditions at Green River. These mixes contain calcium aluminate cement as the bonding phase. This type of cement is commonly used in refractory concrete mixes exposed to temperatures above 500°F (260°C) and can withstand mildly acidic conditions (pH>4). However, hydraulic bonded concrete may not be suitable for use in wet stacks where the pH of the condensate can be less than 4. Chemically bonded mixes containing silicate binders (such as Sauereisen No. 33) are generally considered to be more acid-resistant than hydraulic cement, yet none are in use under high sulfur coal environments. One limitation of the inorganic concretes is that the weight penalty of relatively thick (1-1/2 inch; 38 mm) linings could make them unsuitable for use on steel flues designed for organic linings. However, inorganic mixes have been used directly against the steel shell in both new Lawrence stations, and in at least one new station now under construction, so they provide a high temperature material alternative to acid-resistant brick. Since inorganic mixes are commonly anchored to the shell, and can be reinforced with chopped steel fibers, they may be more suitable for use in seismic areas than acid-resistant brick. The only other limitation of these materials is the risk of substrate corrosion in the event of acid condensation. Although even cracked material will provide a physical barrier to minimize acid transport to the substrate, a membrane backing or other means of providing secondary substrate protection would be desirable.

Organic linings used to date have been based primarily on polyester or vinyl ester resin binders, both of which have deteriorated under some type of flue gas operating condition with high sulfur fuel, and commonly on bypass. Resins more resistant to the 300°F (149°C) bypass temperatures and hot acidic conditions appear to be needed if longer life is to be obtained. The fluoroelastomer linings (CXL-2000 and Flakeline 282-X) now appearing in the newer stacks may provide a significant improvement in the performance record of organic linings. Whether the new materials will be able to provide reasonable service lives in hot and wet environments typical of many high sulfur fuel stacks remains to be seen.

High nickel alloys are being seriously considered as liners for wet stack applications by several utilities, so as to avoid loss of generating capacity from unplanned stack failures. These alloys are already being used in the stack breeching area of outlet ducts, and in the bypass duct downstream of the exit damper. One installation with a high nickel alloy stack lining is in the early stages of start-up. However, these alloys are as yet unproven under stack conditions that cycle between wet gas and hot gas.

Wet Gas

For stacks operating under wet conditions only, acid-resistant brick and mortar have given the longest service (4 to 6 years thus far), in spite of problems with the unpressurized stacks weeping through and corroding reinforcing bands at Elrama and Phillips. Experience with an hydraulic bonded concrete (Pre-Krete G-8) which replaced an epoxy lining at Green River, and with a fluoroelastomer lining (CXL-2000) which replaced a fire retardant glass flake-filled polyester lining (Rigiflake 4855) and a mica flake-filled polyester lining (Rigiflake 489) at Bruce Mansfield, has not been long but early (less than one year) failures have not occurred as they have for some organic materials. None of the stations included in this study which burn low sulfur fuel operate with wet stacks.

Wet Gas and Quenched Hot Gas

At Duck Creek, there is no reheat and the bypass gas is quenched to minimize stack temperatures on bypass. A mica flake-filled polyester lining (Flakeline 151) is exhibiting erosion in the lower portion of the stack where the flue gas turns 90 degrees as it exits from the breeching. The erosion is caused by particulate carryover from the absorbers. However, the upper part of the wet stack has given 3-1/2 years of service thus far including one year with high sulfur coal. Quenching the bypass gas may be a factor contributing to the good lining performance other than the erosion problem.

Wet Gas and Hot Gas

Under wet and hot conditions (which could occur when wet stacks are exposed to full bypass) acid-resistant bricks again have the longest service life (but only 2-1/2 years thus far) for high sulfur fuels. The failures reported for wet/hot conditions include a mica flake-filled polyester lining (Flakeline 151) at Conesville and Mill Creek, and an old unidentified brick mortar at Cane Run 4. The steel flue at Conesville was removed and the stack was relined with acid-resistant brick and mortar (Sauereisen No. 65 mortar).

Reheated Gas

La Cygne is the only installation operating with high sulfur fuel and reheated gas conditions (no bypass capability). An inert flake-filled vinyl ester stack lining (Plasite 4005) is beginning to debond after 2 years of service, as have a previous lining of the same material and a flake-filled polyester lining (Rigiflake). With low sulfur fuel and reheated gas conditions, a glass-flake filled polyester lining (Flakeline 103) and unlined Cor-Ten steel have both given good service for 3-1/2 years thus far at Colstrip and Sherburne, respectively. No failures were reported for low sulfur fuel, reheated gas operating conditions.

Reheated Gas and Hot Gas

Most stations have some form of reheat for the scrubbed gas and have emergency bypass capability. Under these conditions, both high sulfur coal installations with organic stack linings have experienced lining failure during bypass operation. A spray-applied topcoat of an inert flake-filled polyester (Rigiflake) blistered badly at Petersburg and an inert flake-filled vinyl ester (Plasite 4005) failed before start-up of the FGD system at Pleasants 1* of Allegheny Power. Two trowel-applied coats of a glass flake-filled polyester (Rigiflake 4850) are being tried at Petersburg and the results are not yet known. At Pleasants, the stack was relined with a thinner coat of Plasite 4005 and the scrubbers are now always on-line to make sure that the stack temperature never exceeds 170°F (77°C). The stack for Pleasants 2 is being lined with acid-resistant brick. Those stations burning high sulfur coal which have not had stack problems, have either acid-resistant brick or inorganic concrete linings (normally applied by guniting).

Stations burning low sulfur coal and providing reheat and bypass have also had good success with acid-resistant brick or inorganic concretes including a chemically bonded type (Sauereisen No. 33). Although the experience time is short, at least four organic lining materials are being used under these conditions; two of the linings are fluoroelastomers at Apache 2 (CXL-1000) and 3 (Flakeline 282-X), one is a glass flake-filled polyester (Rigiflake 480/4800) at Winyah, and one is an inert flake-filled vinyl ester (Plasite 4030) at Cholla 2. However, the lining at Cholla 2 has never been exposed to bypass conditions. At Winyah, where one-half of the flue gas is always bypassed to the stack, the lining has had some spot failures in the area below the scrubbed gas breeching and above the bypassed gas breeching. These spots are scheduled for repair with the same material. Unlined Cor-Ten steel has given 2-1/2 years of service thus far at Milton R. Young without problems under these conditions, so lined flues may not even be required in some cases.

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*Not included in site visits.

STORAGE SILOS

A supply of dry lime (CaO) or limestone ($CaCO_3$) is stored in silos at power plants having FGD systems which utilize these reagents for SO_2 removal. The storage silos are subjected to alkaline conditions, so carbon steel is satisfactory for this service. Consequently, practically all of the FGD installations have carbon steel silos. The only exceptions are a concrete structure at Widows Creek and a concrete wall with a steel bottom at Conesville. Southwest uses a 10 gauge (3.6 mm) Type 304 stainless steel lining in the bottom cone to provide a low coefficient of friction. There are no silos at the Louisville Gas and Electric plants because the slaked carbide lime is delivered as a slurry. There have been no problems with the storage silos.

BALL MILLS AND SLAKERS

Most of the FGD systems included in this study use limestone as the reactant for SO_2 removal and hence have wet ball mills to obtain the desired particle size. Cholla 1 is an exception in that ground limestone is purchased; however, Cholla 2 has a ball mill for on-site grinding of its limestone supply. Typically, the limestone is fed to the mill as 1/4 in. (6 mm) rock and ground to 200 mesh or finer. The water supplied to the mill can be makeup water, reclaimed water (thickener or pond overflow), or a combination of the two. The limestone slurry is sent to a tank for use in the absorber loop. Some of the systems use lime as the reactant and have a slaker to form hydrated lime [$Ca(OH)_2$] from pebbles of quicklime (CaO) and water. The Louisville Gas and Electric plants are an exception in that they receive a slurry of slaked carbide lime from the supplier. Slakers require makeup water rather than reclaimed water because the presence of dissolved sulfates, sulfites, or bisulfites in concentrations greater than 500 mg/l can seriously hinder the production of usable hydrated lime. The slaking temperature should be 190°F (88°C) or more to insure a small hydrate particle. This temperature can be achieved from the heat of reaction if the water-to-lime ratio is kept low enough as is done in a paste slaker. If a slurry slaker is used, the water-to-lime ratio is higher so that the slaking water must be heated to reach 190°F (88°C). The lime slurry is also sent to a tank for use in the absorber loop.

Information on materials of construction for slakers and ball mills is summarized in Table 3-14. All of the lime slakers are constructed of carbon steel and no problems with construction materials have been noted. The ball mills used on the limestone systems all have carbon steel shells, the main differences being that a

Table 3-14

BALL MILLS AND SLAKERS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Type of Water Used for Grinding or Slaking	Materials: Ball Mills	Materials: Slakers	Comments
Alabama Electric Coop.					
Tombigbee 2 & 3	9/78 & 6/79	Pond overflow Kennedy Van Saun	Rubber-lined carbon steel,	None	
Arizona Electric Power Coop.					
Apache 2 & 3	2/79 & 6/79	Makeup water	Rubber-lined carbon steel, Kennedy Van Saun	None	
Arizona Public Service					
Cholla 1	12/73	Not applicable	None	None	Ground limestone is purchased
Cholla 2	5/78	Makeup water	Rubber-lined carbon steel, Kennedy Van Saun	None	
Central Illinois Light					
Duck Creek	7/76	Makeup water	Rubber-lined carbon steel, Kennedy Van Saun	None	
Columbus & Southern Ohio Elec.					
Conesville 5 & 6	1/77 & 4/78	Makeup water	None	Carbon steel	
Commonwealth Edison					
Will County 1	2/72	Thickener overflow	Unlined carbon steel, Allis-Chalmers	None	
Duquense Light					
Elrama	10/75	Makeup water	None	Carbon steel	
Phillips	7/73	Makeup water	None	Carbon steel	
Indianapolis Power & Light					
Petersburg 3	12/77	Makeup water and thickener overflow	Rubber-lined carbon steel	None	
Kansas City Power & Light					
Hawthorn 3 & 4	11/72 & 8/72	Makeup water	None	Carbon steel	
La Cygne 1	6/73	Makeup water	Ni-Hard lined carbon steel	None	About 2/3 of the lining has required replacement
Kansas Power & Light					
Lawrence 4 & 5 (old)	10/68 & 9/71	Not applicable	None	None	Limestone was ground with coal
Lawrence 4 & 5 (new)	1/77 & 4/78	Makeup water	Rubber-lined carbon steel, Kennedy Van Saun	None	
Kentucky Utilities					
Green River	9/75	Makeup water	None	Carbon steel	
Louisville Gas & Electric					
Cane Run 4	8/76	Not applicable	None	None	Receive slurry of slaked lime
Cane Run 5	12/77	Not applicable	None	None	Receive slurry of slaked lime
Mill Creek 3	7/78	Not applicable	None	None	Receive slurry of slaked lime
Paddy's Run 6	4/73	Not applicable	None	None	Receive slurry of slaked lime
Minnkota Power Coop.					
Milton R. Young 2	5/77	Makeup water	None	Carbon steel	
Montana Power					
Colstrip 1 & 2	11/75 & 8/76	Makeup water	None	Carbon steel	

Table 3-14 (CONTINUED)

Utility and Plant	Start-Up Date	Type of Water Used for Grinding or Slaking	Materials		Comments
			Ball Mills	Slakers	
Northern States Power Sherburne 1 & 2	5/76 & 4/77	Makeup water	Unlined carbon steel, Allis-Chalmers	None	
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	Makeup water	None	Carbon steel	
South Carolina Public Service Winyah 2	8/77	Thickener overflow	Rubber-lined carbon steel, Koppers	None	
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	Thickener overflow	Rubber-lined carbon steel	None	
Southern Illinois Power Coop. Marion 4	4/79	Makeup water and thickener overflow	Rubber-lined carbon steel, Koppers	None	
Springfield City Utilities Southwest 1	4/77	Thickener overflow	Rubber-lined carbon steel, Kennedy Van Saun	None	
Tennesse Valley Authority Widows Creek 8	5/77	Pond overflow	Rubber-lined carbon steel, Kennedy Van Saun	None	Required relining after 4,000 hours
Utah Power & Light Huntington 1	5/78	Makeup water and thickener overflow	None	Carbon steel	

[a]Any materials problems identified are indicated under comments.

few are unlined while most have rubber linings. La Cygne is unique in that the mill has a Ni-Hard lining; about 2/3 of the lining has required replacement but the reason for the failure of the Ni-Hard is not known. The rubber-lined ball mill at Widows Creek required relining after 4,000 hours. There were no other reports of materials problems with ball mills. Although the reason for the lining failure at Widows Creek is not known, it is interesting to note that of all the installations visited, only two (Widows Creek and Will County) use reclaimed water for the ball mill and have significant amounts of fly ash in the scrubbing liquor. Thus, there is the potential for fly ash buildup in the mill. The ball mill at Will County is unlined.

PUMPS

Pumps are used for a variety of services in FGD systems such as slurry feed to the prescrubber and absorber spray headers, slurry transfer, sludge transfer, clear water transfer, and clear liquor feed to the mist eliminator wash nozzles. A matrix of pumps used in the FGD systems visited is provided in Table 3-15. Rubber-lined centrifugal pumps are commonly used for moving slurries with generally satisfactory results. Ordinary carbon steel pumps are usually used for clear water transfer. Stainless steel pumps also find substantial usage, especially where only small pumps are required. The experience with pumps has varied widely in the different desulfurization units. Some plant representatives reported that pumps have given little problem, while others cited slurry feed pumps as their most pressing problems in keeping their units on stream. The reasons for these differences are not obvious in all cases but some pump manufacturers have had noticeably more success than others. Some of the causes for failure of rubber linings are:

- Poor quality lining
- Foreign objects in slurry which cause mechanical damage
- Cavitation because of dry operation
- A particularly abrasive slurry with large particles
- Overworking the pump (operating too near maximum capacity)
- Use of undersized pumps.

Foreign objects have damaged the rubber linings in absorber feed pumps at Conesville and Huntington. At the former site, two linings were damaged by pieces of fiberglass from a pH sample trough that fell down and got into the

Table 3-15

PUMPS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Absorber Feed Pumps	Prescrubber Feed Pumps	Slurry Transfer (from Storage Tank) Pumps	Transfer (from Ball Mill or Slaker) Pumps	Sludge or Spent Slurry Transfer Pumps	Clear Water Transfer Pumps	Mist Eliminator Wash Pumps
Alabama Electric Coop. Tombigbee 2 & 3	9/78 & 6/79	A-S-H, R.L.[b]	A-S-H, R.L.	A-S-H, R.L.	Galigher, R.L.	A-S-H, R.L.	Not identified	A-S-H, R.L.
Arizona Electric Power Coop. Apache 2 & 3	2/79 & 6/79	Denver, R.L.	No prescrubber	Ingersoll-Rand, R.L.	Galigher, R.L. - rubber impeller replaced with stainless steel	Moyno (Robbins & Myers)	--	Durco
Arizona Public Service Cholla 1	12/73	Goulds, 317 SS-require maintenance[c]	Goulds, 317 SS-require maintenance[c]	Goulds, 317 SS-require maintenance[c]	Not identified	Not identified	Not identified	317 SS
Cholla 2	5/78	Denver, R.L.	Denver, R.L.	Goulds, R.L.	Galigher, R.L.	Not identified	Not identified	Goulds, SS
Central Illinois Light Duck Creek	7/76	A-S-H and Worthington, R.L.[d] - original natural rubber replaced by neoprene	No prescrubber	Worthington, R.L.[d] - lining and impeller replaced every 3 months	Galigher, R.L.	Not identified	CS	Not identified
Columbus & Southern Ohio Elec. Conesville 5 & 6	1/77 & 4/78	A-S-H, R.L. - 2 linings damaged by foreign objects	Goulds, 316L SS	Galigher, R.L.	Galigher, R.L.	Moyno, R.L. - a lining lost by cavitation during dry operation	Goulds, 316L SS	Goulds, 316L SS
Commonwealth Edison Will County 1	2/72	A-S-H, R.L.	A-S-H, R.L.	A-S-H, R.L.	A-S-H, R.L.	Not identified	Allis-Chalmers, CS	Not identified
Duquesne Light Elrama	10/75	Ingersoll-Rand, Alloy 20 - rapid wear from slurry erosion; numerous changes tried	No prescrubber	Originally Goulds, probably cast iron-changed to Morris, Ni-Hard	Originally Goulds, probably cast iron-changed to Morris, Ni-Hard	A-S-H, R.L.	Goulds, 316SS	Not identified
Phillips	7/73	Same as Elrama	No prescrubber	Originally Goulds, probably cast iron-changed to Morris, Ni-Hard	Originally Goulds, probably cast iron-changed to Morris, Ni-Hard	A-S-H, R.L.	Buffalo Forge, cast iron - failed in 1 week when operated without lines; changed to Goulds, 316SS	Not identified
Indianapolis Power & Light Petersburg 3	12/77	Denver, R.L.	Goulds, SS	Galigher, R.L.	Worthington, R.L.	Worthington, R.L.	Goulds, SS	Goulds, SS
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	Ingersoll-Rand (350 MIR), cast iron	No prescrubber	General Signal (BIF) positive displacement	Not identified	Goulds, special high chrome impellers	Fairbanks-Morse, bronze steel shafts and propellers	Goulds (not presently used)
La Cygne 1	6/73	A-S-H, R.L.-frequent replacement of throat liners can be done in 6 hours (cause: dry run cavitation)	A-S-H, R.L.-frequent replacement of throat liners can be done in 6 hours (cause: dry run cavitation)	Denver, R.L.	A-S-H, R.L.	Not identified	CS body with brass impeller	CS body with brass impeller

Table 3-15 (CONTINUED)

Utility and Plant	Start-Up Date	Absorber Feed Pumps	Prescrubber Feed Pumps	Slurry Transfer (from Storage Tank) Pumps	Transfer (from Ball Mill or Slaker) Pumps	Sludge or Spent Slurry Transfer Pumps	Clear Water Transfer Pumps	Mist Eliminator Wash Pumps
Kansas Power & Light								
Lawrence 4 (old)	10/68	Goulds, HC 250 alloy	No prescrubber	Goulds, HC 250 alloy	Not identified	Not identified	Not identified	Not identified
Lawrence 4 (new)	1/77	R.L. (unspecified)	R.L. (unspecified)	R.L. (unspecified)	Robbins & Myers, R.L. stators and chrome-moly rotors - liners and rotors wear out in 10-15 weeks	Warman, Ni-Hard	Not identified	Not identified
Lawrence 5 (old)	9/71	Ingersoll-Rand (MIR 500), Ni-Hard - 5 years service	No prescrubber	Ingersoll-Rand (MIR 500), Ni-Hard - 5 years service	Not identified	Not identified	Not identified	Not identified
Lawrence 5 (new)	4/78	R.L. (unspecified) - required repacking every 2 or 3 days until gland seal water flow rate was increased	R.L. (unspecified) - required repacking every 2 or 3 days until gland seal water flow rate was increased	R.L. (unspecified)	Robbins & Myers, R.L. stators and chrome-moly rotors - liners and rotors wear out in 10-15 weeks	Warman, Ni-Hard	Not identified	Not identified
Kentucky Utilities								
Green River	9/75	Ingersoll-Rand, R.L. (Schabauer) - twice replaced linings; now using Ni-Hard impellers	Common pumps for prescrubber and absorber	R.L. (unspecified)	R.L. (unspecified)	R.L. (unspecified)	CS	Not identified
Louisville Gas & Electric								
Cane Run 4	8/76	Gardner-Denver, R.L. - lining problems	Common pumps for prescrubber and absorber	Not identified	Not identified	316 SS (unspecified)	Not identified	Not identified
Cane Run 5	12/77	Denver, R.L.	No prescrubber	CS	CS	(Moyno, Robbins & Myers), SS rotor and rubber stator	Not identified	Not identified
Mill Creek 3	7/78	Ingersoll-Rand, R.L. - lining problems	Common pumps for prescrubber and absorber	Not identified	Not identified	Not identified	Not identified	Not identified
Paddy's Run 6	4/73	A-S-H, Ni-Hard	No prescrubber	CS	CS	A-S-H, R.L.	Not identified	Not identified
Minnkota Power Coop.								
Milton R. Young 2	5/77	A-S-H, R.L.	No prescrubber	Fly ash slurry-Ni-Resist; lime slurry - R.L.	R.L. (unspecified)	Worthington, R.L.	CS	Not identified
Montana Power								
Colstrip 1 & 2	11/75 & 8/76	A-S-H, R.L.	No prescrubber	Worthington, CS	Worthington, CS	A-S-H, R.L.	Ingersoll-Rand, CS	Not identified
Northern States Power								
Sherburne 1 & 2	5/76 & 4/77	Worthington (10M 234), Ni-Hard #1 - impellers last 6000 to 8000 hours; wear plates last 6 months	Common pumps for prescrubbers and absorber	Worthington, Ni-Hard	Robbins & Myers, CS	Warman, Ni-Hard - linings replaced in 6 to 9 months	Cast iron	Not identified
Pennsylvania Power								
Bruce Mansfield 1 & 2	4/76 & 10/77	R.L. (unspecified)	R.L. (unspecified)	R.L. (unspecified)	R.L. (unspecified)	Ingersoll-Rand, R.L. - valve wear problems	Not identified	Not identified

Table 3-15 (CONTINUED)

Utility and Plant	Start-Up Date	Absorber Feed Pumps	Prescrubber Feed Pumps	Slurry Transfer (from Storage Tank) Pumps	Transfer (from Ball Mill or Slaker) Pumps	Sludge or Spent Slurry Transfer Pumps	Clear Water Transfer Pumps	Mist Eliminator Wash Pumps
South Carolina Public Service Winyah 2	8/77	A-S-H, R.L.	A-S-H, R.L.	Galigher, R.L.	Galigher, R.L.	Not identified	Ingersoll-Rand, un-lined	Not identified
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	Ingersoll-Rand, R.L.	No prescrubber	Ingersoll-Rand, R.L.	Galigher, R.L.[e]	Ingersoll-Rand, R.L.	Not identified	Not identified
Southern Illinois Power Coop. Marion 4	4/79	Ingersoll-Rand, R.L.	Ingersoll-Rand, R.L.	A-S-H, R.L.	A-S-H, R.L.	A-S-H, R.L. and Dorr-Oliver	A-S-H, R.L.	Worthington, cast iron
Springfield City Utilities Southwest 1	4/77	Denver (SLR), R.L.	Not identified	A-S-H, R.L.	A-S-H, R.L.	A-S-H, R.L.	Not identified	Not identified
Tennessee Valley Authority Widows Creek 8	5/77	A-S-H, R.L.	A-S-H, R.L.	A-S-H, R.L.	A-S-H, R.L.	A-S-H, R.L.	Probably A-S-H, R.L.	Probably A-S-H, R.L.
Utah Power & Light Huntington 1	5/78	Galigher, R.L. - foreign objects tore some linings	No prescrubber	Galigher, R.L.	Galigher, R.L.	Galigher, R.L.	Durco, Alloy 20 and 316L SS	Durco, Alloy 20 and 316L SS

[a]Any materials problems identified are indicated under item description.

[b]Abbreviations used are:
A-S-H = Allen-Sherman-Hoff
CS = carbon steel
R.L. = rubber-lined
SS = stainless steel.

[c]Pumps required replacement about every 3,000 hours until a maintenance procedure was established for building up the impellers and housings with additional metal on a regular schedule.

[d]Some Worthington pumps have been replaced by A-S-H pumps because of problems in obtaining replacement parts.

[e]Three pumps have been relined because gravel in the system caused wear.

pumps. Frequent loosening of the pump throat liners occurs at La Cygne because of cavitation when the tank level is not maintained. At Duck Creek, the original natural rubber pump linings were replaced with neoprene after a failure occurred. At Cane Run 4, rubber debonding failures on the rotors were caused by overloading and too high a tip speed; also erosion of the housing linings has occurred. The linings were replaced and the pumps were slowed down. The rubber linings have failed on all ten of the absorber feed pumps at Mill Creek. At Green River, the housing linings have torn loose from the absorber feed pumps, and the impeller linings have eroded from slurry wear and insufficient curing of the rubber. The French-made linings have been replaced twice and this installation is now successfully using Ni-Hard impellers without linings. The prescrubber and absorber feed pumps on new Lawrence 4 are rubber lined, and 60 percent of those on new Lawrence 5 are also rubber lined. Two of the original Ni-Hard pumps from old Lawrence 5 are still in service on the absorber side of the new system. Several of the pumps required repacking every 2 or 3 days and this problem was solved by increasing the flow rate of the gland seal water from 7.5 to 15 gpm (1.7 to 3.4 m^3/hr). The rubber-lined pumps for prescrubber feed, absorber feed, and slurry transfer at Will County have been in service for more than 8 years thus far and have not given any materials problems. The only difficulty has been when the linings were torn up by pieces of a broken isolation valve which got into the system.

All slurry recycle pumps (prescrubber feed, absorber feed, and slurry transfer) at Cholla 1 are constructed of Type 317 stainless steel. These pumps lasted about 3,000 hours because of erosion and had to be replaced. The impellers and housings are now built up with additional metal on a regular maintenance schedule so that the pumps do not need to be replaced as frequently. At Sherburne, the prescrubber feed, absorber feed, and spent slurry transfer pumps have Ni-Hard, Type 1 impellers which require replacement every 6,000 to 8,000 hours. The suction side wear plates last about 6 months. After trying 28 percent chrome-iron and rubber-lined pump internals, plant personnel have chosen the latter as the preferred replacement material. At Milton R. Young, alkaline fly ash is used as the absorber reactant. The fly ash is collected in an electrostatic precipitator and slurried in reclaimed water (thickener overflow) for feeding to the spray tower absorber. The fly ash slurry pump that delivers the feed to the absorber is subjected to one of the most severe erosive conditions in FGD systems. This pump is constructed of an erosion-resistant hard metal, probably Ni-Resist, and no problems have been reported. However, the thickener underflow pump at this installation is rubber-lined and the lining requires replacement every 6 to 9 months because of erosion by the fly ash.

The Duquesne Light Company has studied pump materials fairly extensively at Phillips Station. Their initial selection of a Carpenter 20 steel pump with no lining was based on a 2-year performance guarantee rather than on a preconceived idea that rubber-lined pumps would not withstand the pressure head required for the absorber feed. However, the impellers lasted only about 200 hours. Rather than replace the pumps with rubber-lined pumps, which would be very costly, a search was made for alternative materials for impellers and for use as wear rings in the original pumps. The replacement materials included Type 317 stainless steel, titanium, 20 percent chrome-iron, and CD-4MCu. Impellers made from the best materials would last about 2,500 to 3,500 hours and could not be rebuilt. Recently, cast silicon carbide wear rings have been used to line the casings. They are lower priced than the metal wear rings, although they must be diamond ground. They have now operated in excess of 9,000 hours and appear to be in good condition. Moreover, the housing can be weld-repaired without removing these refractory rings. Segmented silicon carbide wear plates have also been developed for the housing, and have been in service for 4,200 hours without evident wear. They are epoxy-bonded to the steel. Silicon carbide is now being tried for impellers and look excellent after 2,000 hours. However, when the pump ran dry and then was hit by a slug of water from sudden opening of a valve, the impeller shattered. A rubber-lined pump tried at Elrama looked good so a change may be made to rubber-lined pumps sometime in the future.

PIPING AND VALVES

The piping used in FGD systems is required to handle alkaline makeup slurry, recycle and discharge slurry, and reclaimed water. The type of material selected depends to a large extent on the type of service encountered. The piping that handles the recycle slurry is subjected to the most severe service conditions, while the piping that handles the alkaline makeup slurry does not require the acid resistance that is needed for the recycle or discharge lines. The reclaimed water piping is not subjected to the erosive conditions encountered with slurries. The piping used in FGD systems is predominantly rubber-lined carbon steel which is selected for its erosion and corrosion protection capabilities. However, significant amounts of fiberglass-reinforced plastic (FRP) and Type 316L stainless steel are utilized as well.

Valves are used in FGD systems for isolation and control functions. Valve problems are generally not materials related but plugging and mechanical problems have frequently occurred. As a consequence, there seems to be a consensus that the number of valves in the system should be kept to a minimum. Rubber-lined valves are the most common, although many stainless steel valves are used. Four types of valves are employed: knifegate, plug, pinch, and butterfly. The data on piping and valves obtained for the various installation visited are presented in Table 3-16.

Slurry Piping

Rubber-lined carbon steel is most commonly used to deliver the alkaline makeup slurry, and this material has provided generally good service. There has been lining wear in high-velocity regions at the La Cygne and Winyah units. Synthetic rubber lining appears to be giving better service than natural rubber in this application. The longest operating life has been at Will County where the reducers eroded and were replaced after 6 or 7 years. Unlined carbon steel has been used to carry the alkaline makeup slurry without encountering erosion problems at several of the lime scrubbing installations including 6-1/2 years of operation thus far at Phillips. FRP has been used at a few sites, but has suffered from erosion at Cholla 1, Duck Creek, and Cane Run 4, and joint failure at Southwest. Use has been made of Type 316L stainless steel to carry the makeup slurry at Green River and there have been no problems after 4-1/2 years of operation.

The slurry recycle and discharge lines are either rubber-lined carbon steel or FRP. Problems similar to those encountered on the makeup slurry lines have occurred. Debonding of the rubber lining occurred at Widows Creek. Erosion of the lining occurred at Sherburne and pieces of rubber plugged spray headers and nozzles. When the lining was intentionally removed, the carbon steel eroded badly at reducers and elbows. The recycle slurry is particularly abrasive at Sherburne because alkaline fly ash is used as the scrubbing reagent. The other installations where this reagent is used (Colstrip and Milton R. Young) have experienced erosive wear of the rubber-lined recycle piping. At Sherburne, FRP is being used to replace the rubber-lined carbon steel. The original installations at Lawrence also used FRP to replace rubber-lined carbon steel which had eroded. However, at Hawthorn, rubber-lined carbon steel was used to replace FRP recycle slurry piping because the latter was too difficult to handle during maintenance to remove plugs and during piping changes.

Table 3-16

PIPING AND VALVES--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Slurry Piping: To Scrubber	Slurry Piping: Recycle & Discharge	Reclaimed Water Piping	Spray Headers	Isolation Valves	Control Valves
Alabama Electric Coop. Tombigbee 2 & 3	9/78 & 6/79	FRP[b]	CS rubber-lined	FRP	CS rubber-lined & clad	DeZurik rubber-lined plug valves	CS butterfly
Arizona Electric Power Coop. Apache 2 & 3	2/79 & 6/79	CS rubber-lined	CS rubber-lined for recycle; FRP for discharge	CS rubber-lined	316L SS	DeZurik rubber-lined plug valves; drain valves are 316L SS	Keystone butterfly with Bakelite discs and rubber seats
Arizona Public Service Cholla 1	12/73	316L SS - no problems; FRP - elbows eroded; CS rubber-lined - blistered		None	316L SS	CS rubber-lined butterfly	CS rubber-lined butterfly; CD-4MCu with CS orifice & Stellite insert - erosion/corrosion required Al_2O_3 orifice plate
Cholla 2	5/78	CS rubber-lined for pipe above 4 inches (100 mm), FRP for smaller		None	317L SS	DeZurik rubber-lined plug valves	Keystone butterfly, rubber-lined
Central Illinois Light Duck Creek	7/76	FRP - erosion at elbows	FRP - erosion at elbows	FRP & concrete	FRP - ME wash was PVC, but lacked heat resistance	Rubber pinch valves replaced DeZurik rubber-lined plug valves	Rubber pinch valves
Columbus & Southern Ohio Elec. Conesville 5 & 6	1/77 & 4/78	FRP	CS rubber-lined	FRP - joints separated under pressure; now CS rubber-lined	FRP	CS rubber-lined or rubber diaphragm	DeZurik CS rubber-lined plug valves
Commonwealth Edison Will Co. 1	2/72	CS rubber-lined for pipe above 4 inches (100 mm), FRP for smaller		CS unlined	CS rubber-lined to absorber; 316L SS inside	Large valve Mosser NI-Resist; small valves DeZurik butterfly, 316L SS	Same as isolation valves; spent slurry rubber pinch valve lasted 250 hours; now butterfly
Duquesne Light Elrama	10/75	CS unlined	CS rubber-lined & FRP SS at thickener	Not identified	316L SS	DeZurik plug valves - erosion	Rubber pinch valves - liners replaced
Phillips	7/73	CS unlined	CS rubber lined CS plastic-lined (Kelolite) for thickener underflow-eroded; now FRP SS at thickener	Not identified	316L SS	DeZurik plug valves - erosion	DeZurik plug valves - eroded; now rubber pinch valves

Table 3-16 (CONTINUED)

Utility and Plant	Start-Up Date	Slurry Piping: To Scrubber	Slurry Piping: Recycle & Discharge	Reclaimed Water Piping	Spray Headers	Isolation Valves	Control Valves
Indianapolis Power & Light Petersburg 3	12/77	CS rubber-lined	CS rubber-lined	FRP - some replaced with CS polypropylene-lined (Kelolite)	Not identified	Hilton 316L SS knifegate & DeZurik cast steel plug valves for ME wash	Hilton 316L SS knifegate & CS rubber-lined butterfly
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	CS unlined	FRP - replaced with CS rubber-lined	CS unlined	316L SS	316L SS knifegate replaced DeZurik plug valves; some SS ball valves with Teflon seals	316L SS knifegate replaced DeZurik plug valves; some SS ball valves with Teflon seals
La Cygne 1	6/73	CS rubber-lined-natural gum changed to synthetic (Telex 200) for better wear resistance		CS rubber-lined	CS rubber-lined	Fabri 316L SS knifegate valves have lasted 1 year; promising trials with PE-lined butterfly valve & 316L SS plug valve with PE plug & seat (Tuffline)	
Kansas Power & Light Lawrence 4 & 5 (old)	10/68 & /9/71	CS rubber-lined-eroded; changed to FRP & PVC		CS rubber-lined	CS rubber-lined	316L SS knifegate	Plug and butterfly valves
Lawrence 4 & 5 (new)	1/77 & 4/78	FRP with abrasion-resistant liner & CS rubber-lined to pond on Unit 5		CS rubber-lined	FRP	316L SS knifegate	Plug valves replaced with gate valves because of incomplete shut off; some butterfly valves
Kentucky Utilities Green River	9/75	316L SS & CS rubber-lined	CS rubber-lined & FRP	CS rubber-lined	FRP	DeZurik 316L SS knifegate	DeZurik 316L SS plug valves
Louisville Gas & Electric Cane Run 4	8/76	FRP Erosion near valves; use rubber-lined spool pieces	FRP	FRP	FRP	DeZurik 316L SS knifegate-packing seal leaks	316L SS butterfly
Cane Run 5	12/77	FRP	FRP	FRP	FRP	None	316L SS DeZurik knifegate
Mill Creek 3	7/78	Same as Cane Run 4, but not operated enough to determine problems					
Paddy's Run 6	4/73	CS	FRP	FRP	FRP	DeZurik 316L SS knifegate - do not seat well	DeZurik 316L SS knifegate
Minnkota Power Coop. Milton R. Young 2	5/77	CS unlined	CS rubber-lined - erosion; <3 inch (75 mm) lines are 316L SS	CS rubber-lined	CS rubber-lined	DeZurik rubber-lined plug valves - erosion	R.K.L. rubber-lined pinch valves
Montana Power Colstrip 1 & 2	11/75 & 8/76	CS rubber-lined	CS rubber-lined - recycle line elbows last 6 mos. & discharge line 12 mos.	FRP - underground lines shock damaged; will change to CS rubber-lined	CS rubber-lined	DeZurik rubber-lined plug valves - eroded; now R.K.L. rubber-lined pinch	DeZurik rubber-lined plug valves - eroded; now R.K.L. rubber-lined pinch valves

Table 3-16 (CONTINUED)

Utility and Plant	Start-Up Date	Slurry Piping: To Scrubber	Slurry Piping: Recycle & Discharge	Reclaimed Water Piping	Spray Headers	Isolation Valves	Control Valves
Northern States Power Sherburne 1 & 2	5/76 & 4/77	CS rubber-lined-breakoff led to removal & erosion of steel; replacing with FRP. FRP at thickener underflow replaced with 316L SS and carbon steel		CS unlined	FRP	Hilton kinfegate - poor sealing	DeZurik rubber-lined plug valves
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	CS rubber-lined	CS rubber-lined	FRP - joint failure & cracking; now CS unlined	Not identified	Knifegate & plug valves	Knifegate
South Carolina Public Service Winyah 2	8/77	CS rubber-lined above 2 inches (50mm) - eroded in high velocity area; 316L SS for small piping	FRP	FRP	316L SS	316L SS knifegate - leakage	316L SS knifegate - leakage
South Mississippi Elec. Power R. D. Morrow 1 & 2	9/78 & 6/79	CS rubber-lined	FRP	FRP	FRP in absorber; 316L SS in duct-corroded in 3 weeks; removed	DeZurik rubber-lined plug valves	DeZurik rubber-lined plug valves
Southern Illinois Power Coop. Marion 4	4/79	CS rubber-lined	CS rubber-lined	FRP	316L SS	DeZurik rubber-lined plug valves and rubber-lined butterfly valves	Large-316L SS knifegate; small-rubber-lined pinch valves
Springfiled City Utilities Southwest 1	4/77	FRP-failure at joints	Recycle piping is CS rubber-lined; all other is FRP-failure at joints	FRP	FRP & CS rubber-lined	DeZurik rubber-lined plug valves - erosion	DeZurik rubber-lined plug valves - erosion
Tennessee Valley Authority Widows Creek 8	5/77	CS rubber-lined - debonding at elbows	CS rubber-lined	CS polypropylene-lined (Kelolite)	316L SS - erosion in venturis; 304L SS used temporarily	Not identified	316L SS knifegate
Utah Power & Light Huntington 1	5/78	CS unlined	CS rubber-lined; ME wash is FRP	FRP	CS rubber-lined and clad with Ceilcrete 2500AR	Grinnell rubber-lined plug valves & Media rubber-lined butterfly	R.K.L. rubber-lined pinch valves; CS, SS, & brass gate valves on discharge lines - brass valves do not last long

[a]Any materials problems identified are indicated under item description.

[b]Abbreviations used are:
FRP = glass-fiber-reinforced plastic
CS = carbon steel
SS = stainless steel
PE = polyethylene
PVC = polyvinyl chloride.

Reclaimed Water Piping

The reclaimed water piping, which carries less solids, has been made of FRP at the majority of the locations. A few cases of failure of the FRP piping at joints have been reported, but results in general have been good. A water hammer broke some of the FRP pipe at Conesville and Bruce Mansfield. Flanged or shop fabricated joints are preferable to field-cemented joints because pipefitters are not skilled in making FRP joints. Where carbon steel piping is used in this application, it is about equally divided between unlined and rubber-lined, with two installations using a polypropylene lining. No problems have been reported for these materials.

Spray Headers

The materials chosen for the spray headers which are located inside prescrubbers and absorbers are primarily Type 316L stainless steel and FRP, with each having about the same amount of usage. At Cholla 2, Type 317L stainless steel was selected to obtain greater corrosion resistance as a result of its additional molybdenum content. No difficulties were reported for FRP in this service, but Type 316L stainless steel underwent erosion in the venturi at Widows Creek. Rubber-lined and clad carbon steel has been used successfully at six stations including La Cygne, where the spray headers have been in operation for more than 6-1/2 years thus far. A mat-reinforced polyester cladding (Ceilcrete 2500AR) on rubber-lined carbon steel is utilized at Huntington and no problems have occurred thus far.

Isolation Valves

Type 316L stainless steel knifegate valves have been used for isolation functions, especially at high pressures where metal is required. However, FRP has been utilized for low pressure service. Although leakage tends to be a problem, there have been no reports of serious corrosion of stainless steel knifegate valves.

Rubber-lined plug valves have also been used for isolation functions and have encountered erosive wear at six stations. All but one of these stations (Southwest) have considerable amounts of fly ash in the recirculating slurry. These valves have been used successfully at six stations, all of which have electrostatic precipitators for fly ash removal except for Cholla 2. The reason for the successful operation at Cholla 2, where the scrubbing liquor contains fly ash, is not known. Rubber-lined plug valves have been successfully replaced with pinch valves at Colstrip, where they have been in service for about 3 years thus far, and at Duck Creek. At the latter site, the valves were replaced because of operating problems rather than erosion. Butterfly valves with rubber linings have been used for isolation applications at only a few sites, and no problems have occurred with them.

Control Valves

For control functions, rubber-lined plug valves have had erosion problems. Rubber pinch valves have been successful but periodic liner replacement is required when they are subjected to high velocity flow. Rubber-lined butterfly valves and Type 316L stainless steel knifegate valves appear to be giving satisfactory performance where they have been used for flow control. An exception is at La Cygne where stainless steel knifegate valves have an average lifetime of only one year. The problem is erosion caused by the scrubbing slurry, which contains 27 percent solids, when the valves are partially closed to control the flow. Trials of polyethylene-lined butterfly valves and valves with polyethylene plugs and seats have been promising at this site. At Phillips and Colstrip, eroded rubber-lined plug valves have been successfully replaced with rubber pinch valves. However, at Will County, the original rubber pinch valves on the spent slurry line lasted only 250 hours and were successfully replaced with butterfly valves.

In general, the performance of valves is site specific and depends on the amount of throttling that is done, as well as on the particle size in the slurries and the pH of the liquid. For example, at Cane Run 4, valve problems accounted for 42 percent of the maintenance on the FGD system. As pointed out above, the trend in scrubber design is to reduce the number of valves in the system to the absolute minimum.

TANKS AND THICKENERS

Tanks are used for a variety of services in an FGD system including slurry recycle, slurry storage, slurry transfer, sludge storage, reclaimed water storage, and mist eliminator washing. As the names imply, the tanks handle slurry, sludge, or clear water. Thickeners can be considered as specialized tanks for sludge dewatering. Tanks have generally been constructed of carbon steel, and many are protected with some kind of lining. The organic linings used in tanks include rubber, flake- (mica, glass, or other inert) filled polyester, mat-reinforced epoxy, coal tar epoxy, and bitumastic. However, where pH is high the use of unlined carbon steel is common. Concrete and FRP tanks have also found usage.

Table 3-17 is a matrix for tanks at the FGD systems visited. The tanks are listed under major headings according to function. The various kinds of tanks are discussed below. Overall, few problems were reported for this component.

Slurry Recycle Tanks

The recycle tanks which provide the slurry feed to the absorber (absorber feed tanks) may be either a separate tank or the bottom of the absorber. Carbon steel with some form of glass flake-filled polyester lining is the most common construction material for these tanks. The tank linings have been generally successful, but some failures have been reported. At Hawthorn, the organic lining failed and was replaced with Type 316L stainless steel. At Sherburne 2, the mica flake-filled polyester lining (Flakeline 151) debonded between layers and was replaced by an epoxy lining (Flakeline E). Not enough specifics regarding lining materials, surface preparation, lining application, and absorber operating conditions are available to pinpoint causes of lining failures when they have occurred. No failures were reported in rubber-lined recycle tanks, nor were any reported in tanks with mat-reinforced epoxy linings.

Unlined carbon steel or Cor-Ten steel is used for absorber feed tanks at Lawrence 4 and 5 (old and new units), Cane Run 4, and Paddy's Run. No problems were reported, but high pH would be important for successful use. Concrete recycle tanks have also been used successfully without linings at Green River, Cane Run 4, and Mill Creek. With the exception of the new units at Lawrence, all of the installations having unlined recycle tanks utilize lime as the scrubbing reagent and, hence, would be expected to have a higher pH in the recycle tank than with limestone, as the reagent. At Southwest where the reagent is limestone, the concrete recycle tank is lined with a glass flake-filled polyester which is performing successfully. At one of the installations where the bottom of the absorber serves as the recycle tank (Huntington), the construction materials are acid-resistant bricks applied over a glass flake-filled polyester lining (Flakeline 103) on carbon steel. Most units have experienced little or no problems with their absorber feed tanks.

The recycle tank which feeds the prescrubber (in those units which employ a prescrubber ahead of the absorber) is often the same common tank which feeds the absorber; this is so indicated in the matrix. In other cases, the slurry feed

Table 3-17

TANKS AND THICKENERS--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Slurry Recycle Tanks: Absorber Feed	Slurry Recycle Tanks: Prescrubber Feed	Slurry Storage Tanks	Slurry Transfer Tanks	Sludge Storage Tanks (Waste Slurry Sump)	Clear Water Tanks: Thickener or Pond Overflow	Clear Water Tanks: Mist Eliminator Wash	Thickener
Alabama Elec. Coop. Tombigbee 2 & 3	9/78 & 6/79	CS[b], Resista-Flake 1151[c] lining	Common with absorber feed tank	CS, Resista-Flake 1151 lining	CS, Resista-Flake 1151 lining	CS, Resista-Flake 1151 lining	None	CS, Resista-Flake 1151 lining	None
Arizona Elec. Power Coop. Apache 2 & 3	2/79 & 6/79	CS, Flakeline 103 lining	None	CS, no lining	CS, no lining	Not identified	None	None	None
Arizona Public Service Cholla 1	12/73	CS, Flakeline 103 lining-lining has required some patching, sometimes from weld damage	Same lining and experience as absorber feed tank	None	None	Same lining and experience as absorber feed tank	None	None	None
Cholla 2	5/78	CS, Coroline 505AR lining	CS, Coroline 505AR lining (tank is bottom of absorber)	CS, Coroline 505AR lining	CS, Coroline 505AR lining	CS, Coroline 505AR lining	None	None	None
Central Illinois Light Duck Creek	7/76	CS, rubber lining	None	CS, rubber lining	CS, rubber lining	None	None	FRP	None
Columbus & Southern Ohio Elec. Conesville 5 & 6	1/77 & 4/78	CS, Corrosioning glass flake/polyester lining	None	CS, no lining	FRP	Not identified	CS, no lining	FRP	CS sides and concrete bottom; bottom has epoxy lining - problem in obtaining seal where concrete joins steel
Commonwealth Edison Will County 1	2/72	CS, 3/16 in. (5 mm) gum rubber lining	CS, 3/16 in. (5 mm) gum rubber lining	CS, 1/4 in. (6 mm) gum rubber lining	Concrete, no lining	Not identified	Not identified	None	CS sides and concrete bottom; no lining
Duquesne Light Elrama	10/75	CS, Coroline 505AR lining (tank is bottom of absorber)	None	Concrete, Ceilcote lining	Not identified	Not identified	CS, Flakeline 103 lining	None	CS sides with Flakeline 103 lining and concrete bottom with Ceilcote lining
Phillips	7/73	CS, Coroline 505AR lining (tank is bottom of absorber)	None	Concrete, Ceilcote lining	Not identified	Not identified	CS, Flakeline 103 lining	None	CS sides with Flakeline 103 lining and concrete bottom with Ceilcote lining
Indianapolis Power & Light Petersburg 3	12/77	CS, Corrosioneering glass flake/polyester lining	None	CS, no lining	CS, no lining	Concrete, no lining	CS, Carbomastic 14 lining	FRP	CS sides and concrete bottom; Carbomastic 14 lining
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	CS, 316L SS lining-replaced Ceilcote lining (tank is bottom of absorber)	None	CS, no lining	CS, no lining	None	CS, no lining	None	CS sides and concrete bottom; lining not identified
La Cygne 1	6/73	CS, rubber lining	Common with absorber feed tank	CS, rubber lining	CS, rubber lining	None	None	None	None
Kansas Power & Light Lawrence 4 & 5 (old)	10/68 & 9/71	CS, no lining	None	None	None	CS, no lining	None	None	None
Lawrence 4 (new)	1/77	Cor-Ten steel, no lining	Cor-Ten steel, no lining	CS, no lining	CS, no lining	None	Not identified	Not identified	Cor-Ten steel sides and concrete bottom; no lining
Lawrence 5 (new)	4/78	CS, no lining	Common with absorber feed tank	CS, no lining	CS, no lining	None	None	Not identified	None

Table 3-17 (Continued)

Utility and Plant	Start-Up Date	Slurry Recycle Tanks		Slurry Storage Tanks	Slurry Transfer Tanks	Sludge Storage Tanks (Waste Slurry Sump)	Clear Water Tanks		
		Absorber Feed	Prescrubber Feed				Thickener or Pond Overflow	Mist Eliminator Wash	Thickener
Kentucky Utilities Green River	9/75	Concrete, no lining	Common with absorber feed tank	CS, no lining	CS, no lining	None	None	None	None
Louisville Gas & Electric Cane Run 4	8/76	Concrete, no lining	Common with absorber feed tank	CS, no lining	None	None	CS, no lining	None	CS, no lining
Cane Run 5	12/77	CS, no lining	None	CS, no lining	None	None	CS, no lining	None	CS and concrete bottom; no lining
Mill Creek 3	7/78	Concrete, no lining	Common with absorber feed tank	CS, no lining	None	None	CS, no lining	None	CS, no lining
Paddy's Run 6	4/73	CS, no lining - some corrosion on outside of tanks where welded to base because of poor welding	None	CS, no lining - some corrosion at base welds	None	None	CS, no lining	None	CS, no lining
Minnkota Power Coop. Milton R. Young 2	5/77	CS, Flakeline 103 lining (tank is bottom of absorber)	None	CS, Dudick lining	CS, Dudick lining	Not identified	CS, Dudick lining - same materials for clarifier overflow tank	Common with clarifier overflow tank	CS, Dudick lining - same materials for clarifier; problems with adhesion on thickener
Montana Power Colstrip 1 & 2	11/75 & 8/76	CS, Rigiflake 4850 lining (tank is bottom of absorber)	None	CS, Rigiflake 4850 lining	CS, Rigiflake 4850 lining	CS, Rigiflake 4850 lining	None	CS, Rigiflake 4850 lining - also for Koch tray wash	None
Northern States Power Sherburne 1	5/76	CS, Flakeline 151 lining (tank is bottom of absorber) - some patching required	Common with absorber feed tank	CS, no lining	CS, no lining	None	CS, no lining	Common with thickener overflow tank	CS, no lining
Sherburne 2	4/77	CS, Flakeline 151AR lining (tank is bottom of absorber) - lining debonded between layers and was replaced by Flakeline E in 1978	Common with absorber feed tank	CS, no lining	CS, no lining	None	CS, no lining	Common with thickener overflow tank	CS, no lining
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	CS, Rigiflake 4850 lining (tank is bottom of absorber	CS, Rigiflake 4850 lining (tank is bottom of prescrubber)	CS, Rigiflake 4850 lining	CS, rubber lining - lining probably unnecessary	None	CS, Rigiflake 4850 lining	Common with thickener overflow tank	CS, glass flake/polyester lining
South Carolina Public Service Winyah 2	8/77	CS, rubber lining	CS, rubber lining	CS, rubber lining	CS, no lining	None	CS, rubber lining	None for fresh water; common with pond overflow tank for recycle water	CS, rubber lining - no longer in use
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	CS, glass flake/polyester lining	None	CS, glass flake/polyester lining	CS, no lining	Concrete, no lining	CS, bitumastic lining	FRP - replaced CS with glass flake/polyester lining for unknown reason	CS, epoxy lining
Southern Illinois Power Coop. Marion 4	4/79	CS, Resista-Flake 1103 lining; cover has Resista-Flake 1251 lining	Common with absorber feed tank	CS, rubber lining	CS, rubber lining	Concrete, bitumastic lining	CS, Flakeline 103 lining	CS, coal tar epoxy lining	CS sides and concrete bottom; bitumastic lining
Springfield City Utilities Southwest 1	4/77	Concrete, glass flake/polyester lining	CS, glass flake/polyester lining	CS, no lining	CS, no lining	Not identified	Not identified	CS, glass flake/polyester lining	CS sides and concrete bottom; bitumastic lining but uncertain if bottom is lined

Table 3-17 (Continued)

Utility and Plant	Start-Up Date	Slurry Recycle Tanks		Slurry Storage Tanks	Slurry Transfer Tanks	Sludge Storage Tanks (Waste Slurry Sump)	Clear Water Tanks		Thickener
		Absorber Feed	Prescrubber Feed				Thickener or Pond Overflow	Mist Eliminator Wash	
Tennessee Valley Authority Widows Creek 8	5/77	CS, 1/4 in. (6 mm) neoprene lining	CS, 1/4 in. (6 mm) neoprene lining	CS, rubber lining	Not identified	Not identified	None	None	None
Utah Power & Light Huntington 1	5/78	CS, ARB over Flakeline 103 lining (tank is bottom of absorber)	None	CS, no lining	CS, no lining	Not identified	CS, Flakeline 103 lining	None	CS, Flakeline 103 lining

[a]Any materials problems identified are indicated under item description.

[b]Abbreviations used are:
ARB = *acid-resistant brick*
CS = carbon steel
FRP = glass-fiber-reinforced plastic
SS = stainless steel.

[c]Trade names of linings are identified by generic type in Table 2-2.

tank for the prescrubber is similar to the recycle tank used for the absorber. Consequently, the experiences with the former are very similar to those with the latter. Thus, it appears that the presence of fly ash in the slurry, which can be more abrasive than limestone or lime, does not create any additional problems with the tank linings.

Slurry Storage Tanks

Tanks used for storing limestone or lime slurry operate at a relatively high pH so that unlined carbon steel has been successfully used at many of the FGD installations. However, some installations use glass flake-filled polyester linings or rubber linings. Part of the reason for using a lining may be the lower pH and/or higher abrasion incurred with a limestone slurry as compared to a lime slurry. A breakdown of the number of limestone and lime units utilizing the three types of slurry storage tanks is as follows:

	Number of Units	
Tank Type	Limestone	Lime
Unlined	8	12
Glass flake-filled polyester lining	5	5
Rubber lining	6	0

In addition, a thick, mat-reinforced epoxy lining (Coroline 505AR) over carbon steel is used with limestone slurry at Cholla 2, and a Ceilcote lining over concrete is used with lime slurry at Phillips and Elrama. The slurry storage tanks have not been cited as a problem area regardless of the materials used.

Slurry Transfer Tanks

The tanks that are used to transfer the limestone or lime slurry from the ball mill or slaker, respectively, are generally unlined carbon steel. The mill recycle sumps at Duck Creek, La Cygne, and Marion are lined with rubber, at Tombigbee with a glass flake-filled polyester (Resista-Flake 1151), and at Cholla 2 with a mat-reinforced epoxy (Coroline 505AR). The mill recycle sump at Will County is unlined concrete. All of the lime slurry transfer tanks are unlined carbon steel except for a rubber lining at Bruce Mansfield, glass flake-filled polyester linings at Milton R. Young and Colstrip, and FRP tanks at Conesville. The utility representative stated that the rubber lining was probably not necessary. No problems were reported for slurry transfer tanks.

Sludge Storage Tanks

Few sludge storage tanks or waste slurry sumps were identified during the plant visits. Of the tanks that were identified, Tombigbee, Cholla 1, Cholla 2, and Colstrip have carbon steel lined with an inert flake-filled polyester or mat-reinforced epoxy, Marion has concrete with a bitumastic lining, Petersburg and R. D. Morrow have unlined concrete, and old Lawrence 4 and 5 had unlined carbon steel. No problems were indicated for these tanks.

Clear Water Tanks

Clear water tanks are for reclaimed water storage (thickener or pond overflow) or mist eliminator washing. The reclaimed water tanks are generally carbon steel with or without a lining. The tank at Winyah was lined with rubber because of high chlorides in the water. However, this is probably unnecessary because it is low pH rather than chlorides that causes problems with carbon steel. In the few instances where mist eliminator wash tanks were identified as part of the FGD system, they were either FRP or carbon steel with an organic lining (inert flake-filled polyester or coal tar epoxy). Only one installation (Sherburne) reported the use of unlined carbon steel for this service. No problems were mentioned for any of the clear water tanks.

Thickeners

Over one-half of the FGD systems listed in Table 3-1 employ thickeners for sludge dewatering. The thickeners are constructed either with a concrete bottom and steel sides or entirely with carbon steel. Various linings (including epoxy) have been used without difficulty. At Conesville, a problem was cited with the seal between the concrete bottom and steel side walls and a solution has not yet been found. The only lining failure reported was at Milton R. Young where adhesion problems occurred for an unknown reason. Several thickeners have been satisfactory without a lining including Will County, new Lawrence 4, and Cane Run 5 which have concrete bottoms, and Cane Run 4, Mill Creek, and Paddy's Run which are entirely carbon steel.

AGITATORS AND RAKES

Agitators for slurry tanks usually have rubber-clad carbon steel blades and shafts. The rubber provides excellent abrasion resistance as well as protection against corrosion. Stainless steel and bare carbon steel agitators are also used in some locations. Type 316L stainless steel agitators are used in the slurry recycle tanks at Milton R. Young and Widows Creek and in the slurry storage tanks at Cholla 1 and 2 without any problems. At Cane Run 4, the agitator blades were originally rubber-clad stainless steel but they were prone to breakage. They were replaced with rubber-clad carbon steel blades which are satisfactory. The smaller size agitators at several locations are constructed of stainless steel. Some quick failures occurred when plain carbon steel agitators were used in slurry recycle tanks at old Lawrence 4 and 5 and at Paddy's Run. At Lawrence, the 3/16-inch (5 mm) thick agitator blades eroded within 3 months, and after they were replaced with blades clad with Devcon plastic/carbide, they did not wear out again. At Paddy's Run, the shaft and blades were replaced after 1 year with rubber-clad carbon steel because of wear. However, plain carbon steel agitators have been satisfactory in some locations where the conditions are not too severe. These include the lime slurry tanks at Hawthorn, Milton R. Young, and Huntington, the bottom of the absorber at Paddy's Run, and the limestone slurry storage and transfer tanks at Sherburne and Will County. A plain carbon steel agitator has also been satisfactory in the fly ash slurry tank at Milton R. Young. This is somewhat surprising in view of the erosive nature of fly ash. The materials problems that have occurred with agitators are minimal. Information on agitators and rakes is summarized in Table 3-18.

Rakes for thickeners are commonly clad with rubber for wear and corrosion resistance, but plain carbon steel rakes are also in use. At Milton R. Young, wear of rubber from the bottom of the paddles has been a problem so that a stainless steel bottom is being considered. There has been some patching of the rubber cladding of the rakes at Phillips and Elrama but, in general, the materials problems that have occurred with this component are minimal.

VACUUM FILTERS AND CENTRIFUGES

If landfilling is used as the method for FGD sludge disposal, additional dewatering of the thickener bottoms is required. This can be accomplished in a vacuum filter or a centrifuge. About one-fourth of the FGD systems listed in Table 3-1 have vacuum filters and only one has a centrifuge (Marion) for sludge dewatering. The filters are the rotary type except at Will County and R. D. Morrow where horizontal belt filters are used. The metal components are carbon steel with or without an organic lining, and the filter cloth is either polypropylene or nylon. The problems have been mechanical rather than related to construction materials. Information on materials of construction for vacuum filters and centrifuges is presented in Table 3-19. The centrifuge at Marion is made of carbon steel.

Table 3-18

AGITATORS AND RAKES--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Agitators	Rakes	Comments
Alabama Electric Coop.				
Tombigbee 2 & 3	9/78 & 6/79	Rubber-clad carbon steel	Not applicable	
Arizona Electric Power Coop.				
Apache 2 & 3	2/79 & 6/79	Rubber-clad carbon steel	Not applicable	
Arizona Public Service				
Cholla 1	12/73	Rubber-clad carbon steel	Not applicable	
Cholla 2	5/78	Rubber-clad carbon steel	Not applicable	Small agitators in limestone tank are Type 316L stainless steel
Central Illinois Light				
Duck Creek	7/76	Rubber-clad carbon steel	Not applicable	
Columbus & Southern Ohio Elec.				
Conesville 5 & 6	1/77 & 4/78	Rubber-clad carbon steel	Not identified	
Commonwealth Edison				
Will County 1	2/72	Rubber-clad carbon steel	Carbon steel	
Duquesne Light				
Elrama	10/75	Rubber-clad carbon steel	Rubber-clad carbon steel	Some patching of cladding on rake
Phillips	7/73	Rubber-clad carbon steel	Rubber-clad carbon steel	Some patching of cladding on rake
Indianapolis Power & Light				
Petersburg 3	12/77	Rubber-clad carbon steel	Not identified	One small mixer has stainless steel shaft
Kansas City Power & Light				
Hawthorn 3 & 4	11/72 & 8/72	Rubber-clad carbon steel	Not identified	Plain carbon steel agitators in lime slurry and slaker hold tanks
La Cygne 1	6/73	Rubber-clad carbon steel	Not applicable	
Kansas Power & Light				
Lawrence 4 & 5 (old)	10/68 & 9/71	Carbon steel; 3/16 in. (5 mm) thick blades	Not applicable	Lasted only 3 months in Unit 4; clad with Devcon plastic/carbide and did not wear out again
Lawrence 4 & 5 (new)	1/77 & 4/78	Rubber-clad carbon steel except for plain carbon	Not identified in Unit 4 Not applicable on Unit 5	Stabilizer fin failure in 1978; replaced by manufacturer; several bearing failures because of improper lubrication
Kentucky Utilities				
Green River	9/75	Rubber-clad carbon steel	Not applicable	Some problems with hub breakage and in gear box to shaft coupling; solved by redesign
Louisville Gas & Electric				
Cane Run 4	8/76	Rubber-clad stainless steel	Not identified	Agitator blades were prone to breakage; replaced with rubber-clad carbon steel
Cane Run 5	12/77	Rubber-clad carbon steel	Not identified	
Mill Creek 3	7/78	Not identified	Not identified	
Paddy's Run 6	4/73	Carbon steel	Not identified	Shaft and blades in recycle tank agitator replaced after 1 year with rubber-clad carbon steel because of wear
Minnkota Power Coop.				
Milton R. Young 2	5/77	Type 316L stainless steel in recycle tanks; carbon steel in slurry tanks	Rubber-clad carbon steel	Wear of rubber from bottom of rake paddles; stainless steel bottoms being considered
Montana Power				
Colstrip 1 & 2	11/75 & 8/76	Rubber-clad carbon steel with Type 316L stainless steel hubs	Not applicable	Some agitators have Type 316L stainless steel shafts

Table 3-18 (CONTINUED)

Utility and Plant	Start-Up Date	Agitators	Rakes	Comments
Northern States Power Sherburne 1 & 2	5/76 & 4/77	Rubber-clad carbon steel in recycle tanks and plain carbon steel elsewhere	Not applicable	
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	Rubber-clad carbon steel	Not identified	
South Carolina Public Service Winyah 2	8/77	Rubber-clad carbon steel	Not identified	Thickener no longer in use
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	Rubber-clad carbon steel	Not identified	
Southern Illinois Power Coop. Marion 4	4/79	Rubber-clad carbon steel	Not identified	
Springfield City Utilities Southwest 1	4/77	Rubber-clad carbon steel	Not identified	Shaft broke in recycle tank agitator because of ultrasonic vibration
Tennessee Valley Authority Widows Creek 8	5/77	Type 316L stainless steel except for plain carbon steel in slurry transfer and storage tanks	Not applicable	
Utah Power & Light Huntington 1	5/78	Rubber-clad carbon steel in recycle tanks; carbon steel in slurry tanks and Type 316L stainless steel in sumps	Not identified	

[a]Any materials problems identified are indicated under comments.

Table 3-19

VACUUM FILTERS AND CENTRIFUGES--MATERIALS OF CONSTRUCTION[a]

Utility and Plant	Start-Up Date	Description of Component	Materials	Comments
Alabama Electric Coop. Tombigbee 2 & 3	9/78 & 6/79	None		
Arizona Electric Power Coop. Apache 2 & 3	2/79 & 6/79	None		
Arizona Public Service Cholla 1	12/73	None		
Cholla 2	5/78	None		
Central Ilinois Light Duck Creek	7/76	None		
Columbus & Southern Ohio Elec. Conesville 5 & 6	1/77 & 4/78	Rotary vacuum filter	Carbon steel with polypropylene cloth	
Commonwealth Edison Will County 1	2/72	Horizontal vacuum filter	Nylon cloth and rubber belt	
Duquesne Light Elrama	10/75	Rotary vacuum filter	Not identified	
Phillips	7/73	Rotary vacuum filter	Not identified	
Indianapolis Power & Light Petersburg 3	12/77	Rotary vacuum filter	Carbon steel clad with Carbomastic; polypropylene cloth	
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	None		
La Cygne 1	6/73	None		
Kansas Power & Light Lawrence 4 & 5 (old)	10/68 & 9/71	None		
Lawrence 4 & 5 (new)	1/77 & 4/78	None		
Kentucky Utilities Green River	9/75	None		
Louisville Gas & Electric Cane Run 4	8/76	None		
Cane Run 5	12/77	None		
Mill Creek 3	7/78	None		
Paddy's Run 6	4/73	Rotary vacuum filter	Carbon steel with polypropylene cloth	
Minnkota Power Coop. Milton R. Young 2	5/77	Rotary vacuum filter	Rubber-clad carbon steel and polypropylene cloth	
Montana Power Colstrip 1 & 2	11/75 & 8/76	None		
Northern States Power Sherburne 1 & 2	5/76 & 4/77	None		
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	None		
South Carolina Public Service Winyah 2	8/77	None		
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	Horizontal vacuum filter	Epoxy clad carbon steel	

Table 3-19 (CONTINUED)

Utility and Plant	Start-Up Date	Description of Component	Materials	Comments
Southern Illinois Power Coop. Marion 4	4/79	Pennwalt-Sharples centrifuge	Carbon steel	
Springfield City Utilities Southwest 1	4/77	Rotary vacuum filter	Carbon steel	
Tennessee Valley Authority Widows Creek 8	5/77	None		
Utah Power & Light Huntington 1	5/78	Rotary vacuum filter	Carbon steel with polypropylene cloth	Some rusting of the frame

[a]Any materials problems are indicated under comments.

SLUDGE POND LININGS

In many cases, the waste product from an FGD system is sent to a pond for disposal, either with or without prior sludge dewatering in a thickener. Information collected on sludge pond lining materials is presented in Table 3-20. No pond problems were reported by the FGD system users. In the case where disposal ponds are used, the preferred lining material for those localities which do not have a low permeability soil is clay. Water table depths also affect whether a pond is a feasible method of waste disposal.

DATA QUALITY

In attempting to document even what materials were used, discrepancies were often uncovered which could only be resolved by tracing down an individual no longer associated with a particular project who provided information based on memory only. Other individuals had to be contacted for information for repair records (often vague) and there was seldom any systematic attempt to document initial properties or monitor performance, much less assess the mode of failure.

In some cases the metal wastage or component failures in the scrubbers included in this program have been documented and the causes have been determined. These circumstances have been discussed in the previous subsections on specific components. However, there are situations in which the parts have been replaced or new materials substituted without any failure analysis to make certain of the cause of the problem.

Specific causes of failures in organic linings could not be determined in most instances because of lack of information necessary to pinpoint the causes. In no case could specific information be obtained regarding a number of important variables in lining application, e.g., quality of surface preparation, degree of skill in application, time between coats, amount of testing for quality of application, weather factors, etc. Moreover, in many instances there was uncertainty regarding designation of the lining. It was not uncommon to hear different descriptions of the same lining from different information sources.

Generally, utility operational people were not familiar enough with inorganic materials used in their systems to know what types of failures might occur or what the causes would be. Invariably, they relied on either a component supplier and/or a materials supplier to provide and install a material either recommended by the contractor or used by another utility. Because no one company has (or

Table 3-20

SLUDGE POND LININGS--MATERIALS OF CONSTRUCTION

Utility and Plant	Start-Up Date	Sludge Pond Linings
Alabama Electric Coop. Tombigbee 2 & 3	9/78 & 6/79	Natural clay-lined pond common to both units
Arizona Electric Power Coop. Apache 2 & 3	2/79 & 6/79	Unlined pond common to both units; 30 acres (12 hectares)
Arizona Public Service		
Cholla 1	12/73	Unlined pond
Cholla 2	5/78	Unlined pond
Central Illinois Light Duck Creek	7/76	Clay-lined pond; 57 acres (23 hectares)
Columbus & Southern Ohio Elec. Conesville 5 & 6	1/77 & 4/78	No pond
Commonwealth Edison Will County 1	2/72	No pond
Duquense Light		
Elrama	10/75	No pond
Phillips	7/73	No pond
Indianaposis Power & Light Petersburg 3	12/77	No pond
Kansas City Power & Light Hawthorn 3 & 4	11/72 & 8/72	Unlined pond common to both units
La Cygne 1	6/73	Unlined pond (shale and limestone layer); 160 acres (65 hectares)
Kansas Power & Light Lawrence 4 & 5 (old)	10/68 & 9/71	Unlined pond common to both units
Lawrence 4 & 5 (new)	1/77 & 4/78	Unlined pond common to both units
Kentucky Utilities Green River	9/75	Unlined pond (natural clay); 9 acres (4 hectares)
Louisville Gas & Electric		
Cane Run 4	8/76	Clay-lined pond
Cane Run 5	12/77	Same Pond as Cane Run 4
Mill Creek 3	7/78	Clay-lined pond
Paddy's Run 6	4/73	No pond
Minnkota Power Coop. Milton R. Young 2	5/77	No pond
Montana Power Colstrip 1 & 2	11/75 & 8/76	Bentonite clay-lined pond common to both units
Northern States Power Sherburne 1 & 2	5/76 & 4/77	Clay-lined pond common to both units; 62 acres (25 hectares)
Pennsylvania Power Bruce Mansfield 1 & 2	4/76 & 10/77	Unlined pond common to both units; 135 acres (55 hectares)
South Carolina Public Service Winyah 2	8/77	Unlined pond; 35 acres (14 hectares)
South Mississippi Electric Power R. D. Morrow 1 & 2	9/78 & 6/79	No pond
Southern Illinois Power Coop. Marion 4	4/79	No pond
Springfield City Utilities Southwest 1	4/77	No pond
Tennessee Valley Authority Widows Creek 8	5/77	Natural clay-lined pond; 100 acres (40 hectares)
Utah Power & Light Huntington 1	5/78	No pond

maintains) information on (1) materials properties and installation procedures, (2) operating conditions, and (3) environmental factors, the information needed for developing failure mechanisms was essentially incomplete.

The lack of useful data appears to be related to the general lack of materials people associated with utilities. Some now have metallurgists or non-materials engineers who follow all materials problems but are generally knowledgeable about only one type of material (usually metals). A & E firms and FGD system suppliers have perhaps more experienced materials people than the utilities, but consider any information they have as proprietary. Materials suppliers usually do not admit that their materials have failed, or blame the failure on application techniques or unknown operating conditions.

The industry appears to suffer from a lack of centralized source of information on materials in general. It appears that utilities, A & E firms, and FGD system suppliers rely on the materials suppliers as the ultimate source of information, and do little or no independent testing except when failures occur, and then legal aspects prevent general dissemination of the information. A coordinated plan of documenting materials quality as it is installed (new or repairs), monitoring performance and operating conditions, and then post-testing materials to determine failure mechanisms appears highly desirable for the industry. This is now done to a limited extent for metals by FGD system suppliers and/or metals companies, but little attention has been given to organic and inorganic materials.

Section 4

COST INFORMATION

The prime objective in selecting construction materials for lime/limestone FGD systems is to choose the most cost-effective or optimum material for each component, i.e., the one meeting the design requirements at the least cost. In addition to initial cost, it is necessary to consider repair and/or replacement cost over the 20 to 30 year design life of the plant when specifying the most economical materials available for the intended service conditions. Certain materials such as organic linings cannot be expected to last the plant lifetime without periodic maintenance touchup and repair. Also, certain small, accessible, easily-replaced parts need not be designed for the life of the plant. At the present time, there is insufficient data available to permit selection of the most cost-effective material for many of the FGD system components. However, the available information on materials costs is presented in this section of the report.

METALS

The relative materials cost and the relative total installed cost for various metals used as piping in FGD systems are shown in Table 4-1. The very large ratios in initial materials cost for corrosion-resistant alloys as compared to carbon steel become substantially smaller when comparing the total installed cost. This drop reflects the labor costs involved in the installation of the piping. Installation costs are based on 50 percent flanged joints and 50 percent welded joints in the 500 feet (152 m) of a complex piping structure. The increased cost of corrosion-resistant alloys explains why plastic pipe or rubber-lined carbon steel has been used extensively in the scrubber systems. Nevertheless, for piping of 3 inch (75 mm) diameter or less, Type 316L stainless steel has been used in several of the FGD systems.

Costs escalate even more rapidly when 1/4-inch (6 mm) alloy plate is compared, as shown in Table 4-2. As was the case with pipe, this difference will be reduced if installed costs are considered. The large cost ratio for corrosion-resistant alloy sheet as compared to carbon steel sheet makes the use of lined carbon steel components seem even more attractive for the absorbers, tanks, and ducts when

Table 4-1

RELATIVE COSTS OF ALLOY PIPE

Material	Cost Ratios for Schedule 40 Pipe[a]					
	Materials Cost Piping and Flanges			Total Installed Cost		
	2-Inch (50 mm) Diameter	4-Inch (100 mm) Diameter	6-Inch (150 mm) Diameter	2-Inch (50 mm) Diameter	4-Inch (100 mm) Diameter	6-Inch (150 mm) Diameter
Carbon Steel	1.00	1.00	1.00	1.00	1.00	1.00
Type 304 SS	3.38	4.41	4.93	1.72	2.21	2.43
Type 316 SS	4.23	5.62	5.80	1.96	2.52	2.80
Carpenter 20	6.58	10.4	12.4	2.75	3.96	4.42
Hastelloy C-276	18.2	19.6	19.7	5.63	7.08	6.42
Hastelloy B	20.6	22.3	22.5	5.94	7.62	7.19

Source: J. Yamartino. Chem. Eng., 85 (26), 138-52 (1978).

[a]For 500 feet (152 m) of pipe in a complex system, with field welding.

Table 4-2

RELATIVE COSTS OF ALLOY SHEET

Material	Cost Ratio per Pound for 1/4-Inch (6 mm) Plate
Carbon Steel	1.0
Cor-Ten	1.3
Type 304 SS	4.0
Type 316 SS	6.0
Carpenter 20	14.1
Hastelloy G	17.5
Inconel 625	22.7
Hastelloy C-276	29.8
Hastelloy B-2	33.5

Source: Compiled from manufacturer's quotations, September, 1979.

considering only the initial cost. An A & E firm provided the following installed cost ratios for absorber vessels:

Construction Material	Relative Cost
Glass Flake/Polyester-Lined Carbon Steel	1.00
Rubber-Lined Carbon Steel	1.15
Type 316L stainless Steel	1.50

ORGANIC LININGS

Power plant representatives were unable to supply any information regarding costs of linings during the on-site visits. The costs of their flue gas desulfurization units was not broken down into individual items of this type. Moreover, cost information available from the lining suppliers was of a very general nature. They pointed out that costs vary from job to job depending upon a number of factors such as particular lining material selected, mode of application (trowel or spray), difficulties imparted by contours of surfaces to be lined, local labor conditions, etc.

The following "ball park" comparisons in the installed costs of linings were supplied by a Dudick representative.

a. Troweled glass flake-filled (80 mils; 2 mm) system about $6/ft^2$ ($65/m^2$).

b. One troweled coat of glass flake and one spray coat of mica-filled material (60 mils; 1.5 mm) about $5/ft^2$ ($54/m^2$).

c. Two spray coats of mica-filled material (40 mils; 1 mm) about 4.25/ft^2 ($46/m^2$).

d. Troweled 1/8-inch (3 mm) linings with chopped-glass fibers about $7/ft^2$ ($75/m^2$).

e. Troweled 1/8-inch (3 mm) linings with glass fiber matting about $6.50/ft^2$ ($70/m^2$).

The comparative performance is reported to be:

a. Five years maintenance free.

b. Two years maintenance free.

c. One year maintenance free.

d. More than five years maintenance free.

e. More than five years maintenance free providing temperature exposure is not above 140°F (106°C).

The use of mica as a filler results in lower costs than the use of glass flake, but mica was also reported to provide much lower barrier properties than glass flake. Glass flake costs $1.08/pound ($2.38/kg) while mica costs 9 cents/pound (20 cents/kg). Moreover, the mica-filled linings are applied by roller, brush, or spray, which further lowers the installed cost.

Another lining supplier provided the following "ball park" figures for linings costs:

- Two trowel coats of glass flake/polyester about $\$7/ft^2$ ($\$75/m^2$).
- The mica filled linings (spray applied) as low as $\$5/ft^2$ ($\$54/m^2$)and as high as $\$9/ft^2$ ($\$97/m^2$).

The lower price mentioned above is for application in open areas where lining is easy to install. Generally the applied cost of a lining divides approximately as follows: 2/3 for installation and 1/3 for material.

This same lining supplier indicated that sheet rubber linings cost about twice as much as the organic linings and another information source indicated that applied costs of rubber linings ranged anywhere from \$15 to $\$25/ft^2$ (\$160 to $\$270/m^2$). Moreover, the neoprene (installed) was 10 to 25 percent more expensive than natural rubber. Another lining supplier compared stainless steel and lined carbon steel as follows: Type 316L stainless steel about $\$36.40/ft^2$ ($\$392/m^2$) and carbon steel with lining \$18.20 + \$6.00 = $\$24.20/ft^2$ (\$196 + \$65 = $\$261/m^2$). This does not include fluoroelastomer linings which cost much more. When first introduced, the fluoroelastomer linings were about \$25 to $\$30/ft^2$ (\$270 to $\$320/m^2$). The price in June, 1979 as supplied by Pullman Power Products is \$35 to $\$40/ft^2$ (\$380 to $\$430/m^2$) on large jobs where there are no obstructions to hinder the work.

As an example of the importance of using a high quality lining, \$200,000 was saved in the cost of lining the stack at Bruce Mansfield by using thin-film, mica-filled lining against the lining supplier's recommendation to use a heavy, trowel-applied glass flake-filled lining. An early failure resulted in a daily lost power cost of \$500,000.

INORGANIC MATERIALS

The major use of inorganic materials in FGD systems is for protective linings in abrasive (venturis) or hot acidic (stacks) environments. Because of the high surface area exposed to the stack environment and usual purchase as a separate component, materials costs are of more concern and more easily recognized than for some other components. Consequently, some cost information was accumulated for stack lining materials during the field survey and is shown below:

Material	Installed Cost, $/ft^2$ ($/m^2$): Range	Typical
Plain steel liner	18-30 (190-320)	25 (270)
Linings		
Glass flake	6-10 (65-110)	8 (90)
Fluoroelastomer	25-60 (270-650)	40 (430)
Inorganic concrete	10-20 (110-220)	15 (160)
Lined steel liner		
Glass flake	25-45 (270-480)	35 (380)
Fluoroelastomer	45-70 (480-750)	65 (700)
Inorganic concrete	30-50 (320-540)	40 (430)
FRP liner	~35 (~380)	--
Acid-resistant brick liner	25-60 (270-650)	30 (320)
Special alloys		
Type 316/317 stainless steel	35-70 (380-750)	50 (540)
Inconel/Incoloy	90-125 (970-1,350)	100 (1,080)
Foam glass	15-20 (160-220)	--

These data illustrate that inorganic concrete lined steel and acid-resistant brick linings are cost-competitive to glass flake lined steel. Installed costs of fluoroelastomer lined steel is about twice, and nickel alloys about three times that of the lowest cost lining materials. However, initial installed costs are only one criterion which may affect a utility's selection of a material. The other factors are design aspects (earthquake zone, amount of chloride in coal, etc.), estimated service life and maintenance costs, and the cost of lost power production associated with any maintenance required. The latter factor appears to be a major reason why some utilities are now considering the use of nickel alloy liners in spite of their three-fold initial cost penalty.

Cost information on inorganic materials used in other FGD system components was not obtained because it was generally unavailable. However, comparative costs of ceramic versus metal spray nozzles should be available from major spray nozzle manufacturers. The cost of inorganic brick linings for venturis would depend on whether "standard" or "custom" shapes are required, but would probably be two to four times higher than the cost of inorganic concrete linings. Because of erosive conditions in venturis, fired shapes are often preferred since they can outlast concretes (with similar aggregates) from two to ten fold. Consequently, initial cost is generally of little concern where severe erosion is encountered. Therefore, hard ceramics like silicon carbide or alumina are being commonly used for spray nozzles and for venturi linings.

PRESENT WORTH ANALYSIS EXAMPLE

Research-Cottrell has performed a present worth analysis for the outlet ductwork for an FGD system for two new 600 MW boilers fired with low sulfur coal (1). The outlet ductwork will be subjected to saturated flue gas containing up to 40 ppm SO_2, some chlorides, some excess oxygen, and some particulate matter. This environment attacks stainless steel alloys mainly by pitting caused primarily by chlorides and secondarily by sulfites. Stagnant conditions where liquid can accumulate, such as in low places, under deposits, or in crevices, accentuate the corrosivity because they interfere with the oxygen supply and they cause differences in electrode potential between one area of the surface and another. Since the bottom surface of the outlet duct can collect condensate, it is subject to more severe attack than the top or the sides.

Research-Cottrell's design philosophy is that the materials selected must have a good probability of surviving without major failure for the full 30 year lifetime of the plant. They recommended Type 316L stainless steel with a 2.75 percent minimum molybdenum content for the duct sides and top, and Type 317L stainless steel with a 4.0 percent minimum molybdenum content for the floor and lower corners. Other alternatives include lined carbon steel or higher alloys such as Uddeholm 904L, Hastelloy G, Inconel 625, and titanium. Although the higher alloys have higher probabilities of survival than the recommended materials, they also have higher costs.

Research-Cottrell's present worth analysis for four materials alternatives for outlet ductwork is summarized in Table 4-3. The assumptions for determining the direct and indirect operating costs for each alternative are shown in Table 4-4. Research-Cottrell's analysis indicates that although glass flake/polyester lined carbon steel has the lowest initial cost, it has the highest total cost over the lifetime of the plant. Higher alloys than the recommended materials have both

Table 4-3

RESEARCH-COTTRELL'S PRESENT WORTH ANALYSIS FOR OUTLET DUCTWORK[a]

Top and Sides	Lined Carbon Steel[b]	316L SS/2.75% Mo[c]	317L SS/4.0% Mo[d]	Uddeholm 904L
Bottom	Lined Carbon Steel[b]	317L SS/4.0% Mo[d]	317L SS/4.0% Mo[d]	Uddeholm 904L
Internals	Lined Carbon Steel[b]	316L SS/2.75% Mo[c]	316L SS/2.75% Mo[c]	Uddeholm 904L
Externals	Carbon Steel	Carbon Steel	Carbon Steel	Type 316L Stainless Steel
Initial Cost, $	2,678,802	2,877,992	3,474,282	4,410,962
Direct Operating Cost, $	1,189,600	882,300	528,900	358,800
Indirect Operating Cost, $	3,640,000	-0-	-0-	-0-
Total, $	7,508,402	3,760,292	4,003,182	4,769,762

Source: Richman, M. "Laramie River 1 & 2 Outlet Duct Analysis: Materials of Construction", Research-Cottrell (March 28, 1977).

[a]Base time period = 1st quarter 1977
Plant lifetime = 30 years
Interest rate = 8%
Total present worth = initial cost
+ present worth of direct operating charges
+ present worth of indirect operating charges
Direct operating charges = materials & labor for maintenance, repair & replacement
Indirect operating charges = cost of boiler downtime required to make repairs and/or replacement of wet ductwork materials, computed as cost of power replacement.

[b]Glass flake/polyester lining applied by trowel to a nominal thickness of 80 mils (2 mm).

[c]Type 316L stainless steel with a 2.75 percent minimum molybdenum content.

[d]Type 317L stainless steel with a 4.0 percent minimum molybdenum content.

Table 4-4

ASSUMPTIONS USED BY RESEARCH-COTTRELL
FOR PRESENT WORTH ANALYSIS

Direct Operating Charges

Alternative No. 1--Carbon Steel Lined with Glass Flake/Polyester

- No charges year 1--warranty
- 10 percent of lining installed cost all other years, except:
- 100 percent of lining installed cost every 5th year
- No charges year 30

Alternative No. 2--Type 316L Stainless Steel with 2.75 Percent Molybdenum

- No charges year 1--warranty
- Charges increase linearly from 0 percent of duct materials cost at startup to 8 percent of duct materials cost at 30 years
- No charges year 30

Alternative No. 3--Type 317L Stainless Steel with 4.0 Percent Molybdenum

- No charges year 1--warranty
- Charges increase linearly from 0 percent of duct materials cost at startup to 4 percent of duct materials cost at 30 years
- No charges year 30

Alternative No. 4--Uddeholm 904L

- No charges year 1--warranty
- Charges increase linearly from 0 percent of duct materials cost at startup to 2 percent of duct materials cost at 30 years
- No charges year 30

Indirect Operating Charges

Alternative No. 1 Only

- Two weeks minimum additional downtime for lining installation every 5 years, based on 10 mills/kWh for power lost

Source: Richman, M. "Laramie River 1 & 2 Outlet Duct Analysis: Materials of Construction", Research-Cottrell (March 28, 1977).

higher initial costs and higher total costs. However, it must be pointed out that these results are based on the assumptions made by Research-Cottrell as shown in Table 4-4. The validity of the results can be determined only from 30 years of actual experience accompanied by careful documentation of costs for materials and labor for maintenance, repair, and replacement, as well as cost of boiler downtime to make repairs and/or replacement of outlet duct materials for each of the four alternatives. This type of verification is extremely difficult to obtain.

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1. Richman, M. "Laramie River 1 & 2 Outlet Ductwork Analysis: Materials of Construction". Research-Cottrell, March 28, 1977.

Section 5

CONCLUSIONS AND RECOMMENDATIONS

The following components have a relatively low history of materials problems and/or are amenable to rapid repair or replacement.

a. Spray nozzles

b. Mist eliminators

c. Fans

d. Inlet ducts

e. Bypass ducts

f. Expansion joints

g. Storage silos

h. Ball mills and slakers

i. Tanks and thickeners

j. Agitators and rakes

k. Vacuum filters and centrifuges

l. Pond linings.

These components do not appear to require any materials research efforts.

The following components have a moderate history of materials problems, which are of moderate importance due to the size of the component, difficulty of repair, availability of materials, or the lack of a standby unit or bypass capability.

a. Prescrubbers

b. Absorbers

c. Reheaters

d. Outlet ducts (to outlet dampers)

e. Dampers

f. Pumps

g. Piping and valves.

Moderate research appears desirable to identify materials failure mechanisms, important environmental factors, and proper design techniques. However, much of this type of information can be developed by post-testing full-scale components, correlating failures with the service environment, and disseminating this information to the industry in the form of a newsletter.

The following components have a significant history of materials problems and are critical components in that failures may require complete boiler shutdown and loss of generating capacity for lengthy periods due to the lack of standby components or bypass capability.

a. Outlet ducts (beyond outlet dampers)

b. Stack linings.

Research efforts for the latter two components need to be directed to:

1. Compiling and maintaining general materials performance data
2. Characterizing environmental conditions where failures are occurring
3. Post-testing materials exposed to FGD environments to determine and/or verify failure mechanisms
4. Laboratory testing of commercial materials to verify property data, and
5. Developing new or improved materials and design concepts based on the above information.

A materials summary, by component, is presented in the following paragraphs.

Alloys have performed quite well in prescrubbers except where chloride attack is a problem. The attack of Type 316L stainless steel by chlorides at low pH levels is causing the selection of higher alloys such as Uddeholm 904L and Incoloy 825 for newer FGD systems. Organic lining materials used to date in prescrubbers appear to be providing corrosion protection when covered with more erosion-resistant materials such as prefired bricks and shapes.

Inorganic concrete linings have had mixed results in prescrubbers. Erosion and cracking both appear to be problems in some prescrubber quench ducts, but the mechanism causing these failures is unknown. Erosion of the cement matrix could occur by three mechanisms in prescrubbers: (1) particulate (reagent and/or fly ash) erosion, (2) water erosion, and (3) chemical attack, all of which could be operating simultaneously to loosen aggregates. No information was obtained by which to distinguish the loss mechanism, nor was there any indication of attempts to study the failing materials. Since erosive wear of refractory concretes is known to be proportional to the particle radius cubed, the particle velocity squared, and inversely proportional to the concrete strength squared, characterization of the particle loading conditions, size, and approximate velocity at those locations having problems would be helpful for selecting materials. To determine whether chemical attack is a factor, post-test strength measurements compared to "typical" data for a specific material would indicate whether the material has a normal strength. If not, chemical analysis and porosity data might be obtained to determine whether the low strength is due to chemical attack or a poor installation job.

Absorbers can be constructed of stainless steel, rubber-lined carbon steel, or organic-lined carbon steel. Stainless steel requires the highest initial investment but is much easier to repair and may require less maintenance than a lining. However, Type 316L stainless steel is not recommended for service in low pH, high chloride environments. Rubber linings provide excellent resistance to chemical attack and abrasion in an FGD system absorber. However, the linings are difficult to repair and raise the possibility of fires caused by accidental ignition from welders' torches. Organic linings over carbon steel provide the lowest initial cost of construction, but their performance has ranged from satisfactory to poor. From the information available at present, certain conclusions are possible regarding the use of organic linings. They are as follows:

- A high-quality lining material should be selected. The minimum quality of lining used in absorbers should be (a) the trowel-applied, glass flake/polyester of 80 mil (2 mm) nominal thickness in areas subject to normal abrasion, and (b) the heavy duty (1/8-inch nominal thickness; 3 mm) fiber mat-reinforced materials containing abrasion-resistant fillers in the high-abrasion areas (wherever slurry is projected against the lining).

- The lining material must be applied by skilled, experienced applicators who will stand by their work.

- The applicator must understand metal surface preparation procedures and employ them properly.

- Careful quality control procedures must be used.

In spite of greater care required to install them, ceramic spray nozzles are now becoming commonly used for slurry service in the newer scrubber systems. Both SiC (silicon carbide) and Al_2O_3 (alumina) materials should provide good erosion resistance. Cost, availability, and design considerations will probably influence the selection of a specific material more than any difference in wear resistance. Stainless steel nozzles appear to be preferred for mist eliminator washing, but ceramic nozzles have also been used for this service.

Chevron mist eliminators constructed of FRP have been satisfactory from the materials standpoint provided the vanes are thick enough to prevent breakage during maintenance and cleaning. It appears safe to conclude that enough experience is available to allow intelligent selection of materials for mist eliminators.

Only in-line reheaters present corrosion problems, and should be constructed of Type 316L stainless steel, Hastelloy G, Inconel 625, or Incoloy 825.

Carbon steel fans ahead of the absorber are the most successful, provided dry particulate removal is good. If a wet fan must be used, i.e., no reheat of the flue gas, Inconel 625 and Incoloy 825 are the materials of choice. With 25° to 50°F (14° to 28°C) of reheat, carbon steel fans can be used after the reheater.

Inlet and bypass ducts are constructed of carbon steel or Cor-Ten steel and are generally not a major problem area. However, the same cannot be said for outlet ducts, especially for sections which handle both hot gas and wet gas. These sections exist on units which have a bypass for scrubber shut down but do not have stack gas reheat, and are located downstream from the bypass junction. Acidic conditions developed during scrubber operation become more severe on bypass as the temperature is raised and other corrosive species in the unscrubbed flue gas (chloride and fluoride) are introduced. Because of the critical nature of the outlet duct in this area (like the stack, a failure requires shutdown), it is important to use long lasting alloys and/or linings in this zone, and probably for a short distance upstream from the outlet dampers of both the bypass and outlet ducts. Although corrosion-resistant alloys appear promising, they are costly and may corrode from chloride build-up in closed-loop systems. Consequently, methods of protecting even these materials may need to be developed.

Satisfactory expansion joint materials are available if careful attention is given to selecting the proper material to fit temperature and condensate conditions. For temperatures up to 400°F (204°C), Viton®/asbestos has generally been satisfactory. Metal expansion joints have been used successfully in some cases, especially under dry conditions. However, even stainless steels can give problems if condensate forms in the joints, and the condensate is high in acid concentration, and/or contains high chlorides.

Inlet dampers constructed of carbon steel or Cor-Ten steel with Inconel 625 or Hastelloy G seals have operated without corrosion. Outlet and bypass dampers require Type 316L stainless steel with Inconel 625 seals to avoid corrosion.

The performance of a stack lining depends on whether the scrubbed gas is delivered to the stack wet or reheated, and whether or not the stack is also used for hot bypassed gas. Acid-resistant brick linings exhibit good performance regardless of operating conditions. However, in spite of their successful use they have two limitations: (1) acid penetration of the brick, mortar, or brick-mortar interface may occur under wet conditions, and (2) they may not be suitable linings in earthquake-prone areas. It remains to be seen whether pressurization of the stack annulus can solve the penetration problem under wet conditions. For seismic areas, a brick working lining and a standby steel lining in the same stack might be feasible if the risk of a single stack failure is to be minimized. Alternatively, high nickel alloys may be considered for stack linings in seismic areas.

Cracking and spalling are problems mentioned for hydraulic bonded concretes used as stack linings. The spalling problem occurred in the upper part of the stack under wet conditions. It is not known whether the damage occurred as a result of freeze-thaw or bond solution phenomena. Cracking of a hydraulic bonded concrete was also reported in an outlet duct which operated for about one year without reheat. Again, no information was obtained as to the mechanism responsible for the cracking. Drying shrinkage is one design factor often overlooked which can cause initial cracking which only later becomes evident.

Since chemically bonded concretes can withstand hot acidic environments, they offer an alternative for stack linings. However, they have a finite permeability (and may crack), so any condensed acid may ultimately reach the substrate to which they are applied. If these materials (or improved varieties) can be demonstrated to provide corrosion protection to the substrate as well as being a primary physical barrier, they have considerable potential for use in FGD system outlet ducts and stacks.

Storage silos for lime or limestone can be constructed of carbon steel without any corrosion problems.

Ball mills for limestone and slakers for lime can be constructed of carbon steel with no problems. The mills usually require a rubber lining to minimize wear and noise.

Rubber-lined pumps are used widely for moving slurries with generally satisfactory results. The most important factor in the design of rubber-lined pumps is the impeller tip speed which should be about 5,000 to 6,000 ft/min (25 to 30 m/sec). Pumps which have been proven in rugged service for slurry transport such as in mining use should be selected. The pumps should be designed for easy replacement of rubber linings and general maintenance.

Carbon steel piping with synthetic rubber lining has performed well in all types of service, although some erosion occurs in high velocity regions. For small diameter pipe (< 3 inch; 75 mm) Type 316L stainless steel can be cost effective.

Valves should be kept to a minimum in the system. Type 316L stainless steel knifegate valves have presented the fewest erosion/corrosion problems.

Tanks have generally been constructed of carbon steel, and many are protected with a rubber or an organic lining. However, where pH is high the use of unlined carbon steel is common. FRP and concrete have also found usage for mist eliminator wash tanks and recycle tanks, respectively. Thickeners can be constructed with concrete bottoms and steel sides or entirely of carbon steel. Various linings have been used without difficulty and in several cases the thickeners have been satisfactory without a lining. Overall, few problems were cited for tanks and thickeners.

Agitators and rakes are usually constructed of rubber-clad carbon steel for protection against erosion and corrosion, and few materials problems have occurred.

Where vacuum filters are used, carbon steel is satisfactory for metal components, although organic linings have been used in some cases. Either polypropylene or nylon cloth is acceptable for the filter material.

In cases where disposal ponds are used, the preferred lining material for those localities which do not have a low permeability soil is clay.

Generally, utility operational people are not familiar enough with materials used in their system to know what types of failures might occur or what the causes would be. Invariably, they rely on either a component supplier and/or a materials supplier to provide and install a material either recommended by the contractor, or used by another utility. Because no one company has or maintains information on (1) materials properties and installation procedures, (2) operating conditions, and (3) environmental factors, the information needed for developing failure mechanisms is essentially incomplete.

The initial installed costs are only one criteria which may affect the selection of a material. The other factors are design aspects (amount of chloride in coal, earthquake zone, etc.), estimated service life, maintenance costs, and the cost of lost power production associated with any repair or replacement required. In order to take all these factors into account, it is necessary to perform a present worth analysis for various materials in a specific FGD component. However, it is difficult, if not impossible, to determine service life and maintenance costs without many years of operating experience for each material under consideration.

The industry appears to suffer from the lack of a centralized source of information on materials in general. It appears that utilities, A & E firms, and FGD system suppliers all rely on the materials suppliers themselves as the ultimate source of their information, and do little or no independent testing except when failures occur. A coordinated plan of documenting materials quality as it is installed (new or repairs), monitoring performance and operating conditions, and then post-testing materials to determine failure mechanisms appears highly desirable for the industry. This is now done to a limited extent for metals by FGD system suppliers and/or metal companies but little attention has been given to organic and inorganic materials.

Research programs are needed on the development of inexpensive materials and methods for lining or protecting outlet ducts and stacks. What is needed is a gunable one-component, acid-resistant inorganic concrete which will not only resist the environmental conditions, but also provide improved protection to the component to which it is applied. Alternatively, the development of a method for cathodic protection of steel substrates in outlet ducts and stack linings should be considered.

Experiments should be performed to determine the effect of additives such as magnesium on the corrosiveness of lime and limestone slurries on metals at various pH's and chloride concentrations. Increased corrosion when magnesium is added to the system may not be simply the result of reduced scale formation, as magnesium chloride solutions are among the worst for causing stress-corrosion cracking. This problem would be greatly exacerbated by closed-loop operation and/or by operation with coals having a relatively high chloride content.

Section 6

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