Manual of Protective Linings for Flue Gas Desulfurization Systems

ASTM STP 837

MANUAL OF PROTECTIVE LININGS FOR FLUE GAS DESULFURIZATION SYSTEMS

A manual
sponsored by ASTM
Committee D-33 on
Protective Coating and Lining Work
for Power Generation Facilities

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Foreword

This publication was sponsored by ASTM Committee D-33 on Protective Coating and Lining Work for Power Generation Facilities. Its creation and maintenance is the responsibility of Subcommittee D33.09 on Protective Linings for Flue Gas Desulfurization Systems. This subcommittee is composed of representatives from various organizations involved with corrosion mitigation of flue gas desulfurization (FGD) systems. Subcommittee members include individuals from utilities, architect-engineer-constructors, FGD system and component suppliers, lining manufacturers and installers, and other interested parties. The information presented herein reflects a consensus of the subcommittee.

This manual was prepared to address a need perceived by ASTM Committee D-33 for guidance in selecting and applying FGD system linings. In addition to serving as that source, this document has the equally necessary role of acting as a focal point for a rapidly changing technology. While the subcommittee considers the information contained in this manual to be state of the art, this emerging FGD technology offers limited historical data upon which to establish detailed requirements or methodologies. Accordingly, the user will find this first edition rather general. It is intended that revisions be made as more specific information becomes available.

It is particularly important to determine the operating characteristics for a given installation and to accurately translate these into specific design criteria. This manual provides a guide for the lining design requirements applicable to a particular FGD project. All parties to the lining work should be cognizant of the anticipated performance criteria and attendant responsibilities.

The guidance offered in this manual presupposes a "wet" type scrubber, that is, one in which the medium for removing sulfur oxides entrained in the flue gas is an alkali suspended or dissolved in water which is injected into the gas stream. This mechanism can be inherently quite corrosive or erosive to the surfaces contacting the scrubbed gas and scrubbing liquor. Other FGD systems are available, including "dry" processes, where the sulfur removal media are recognized as being less corrosive than wet scrubbing media. Nevertheless, this manual will still provide meaningful background to individuals charged with assuring that corrosion concerns in other systems have been adequately addressed.

Related ASTM Publications

Permanence of Organic Coatings, STP 781 (1982), 04-781000-14

Cold Cleaning with Halogenated Solvents, STP 403A (1981), 04-403010-15

Manual of Coating Work for Light-Water Nuclear Power Primary Containment and Other Safety-Related Facilities, 1979, 03-401079-14

Compilation of ASTM Standards in Building Codes, 21st edition, 1983, 03-002183-10

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Chapter 1

General Considerations

Ever since the first practical applications of electricity and the internal combustion engine, our society has continually expanded its uses of energy. Some of the major forms of energy conversion involve combustion of fossil fuels such as gasoline, oil, and coal.

Since the products of combustion can be harmful to our environment, we have committed ourselves (through government actions) to limit the amount of pollutants exhausted into the atmosphere. One of the steps taken has been the use of flue gas desulfurization (FGD) systems to clean exhaust (flue gas) from power generation facilities (Figs. 1-1 and 1-2).

Flue gas desulfurization systems consist of a wide spectrum of chemical process equipment. This equipment is used for reducing sulfur dioxide emissions in flue gas resulting from combustion of fossil fuels.

The design, construction, and operation of desulfurization systems vary among equipment manufacturers and operating power generation facilities, and pose a number of complex material and design problems.

Before the existence of flue gas desulfurization systems, corrosion of chimneys and ductwork was usually avoided by insulating them to maintain gas and surface temperatures above the sulfuric acid dew point. Most FGD systems, however, use water and alkaline materials to contact the flue gas so that the sulfur oxides can be absorbed or reacted into the solution. This "wet" process cools and saturates the flue gas, creating more aggressive, corrosive environments. Carbon steel associated with the flue gas transmission system will be subject to significant corrosive attack under these conditions.

Types of Pollutants and Corrosive Effects

Fossil fuels burned to produce electrical power contain significant amounts of sulfur (and other contaminants). This sulfur reacts with oxygen in the air or oxidizing agents to produce sulfur dioxide (SO_2) along with some sulfur trioxide (SO_3) as products of combustion. For coal, approximately 1 to 3% of the SO_2 in the flue gas is oxidized to SO_3. These oxidation processes occur at high temperatures within the boiler; the SO_3 content is fixed before the flue gas leaves the air preheater and does not increase significantly within the FGD system.

The exact state of the SO_3 in the flue gas at temperatures above the acid dew point is subject to several theories, ranging from that of a gas, to a very fine submicron particulate, to individual SO_3 molecules strongly associated with the adjacent water vapor. The acid will stay in the "vapor" form until the temperature falls below the dew point and sulfuric acid condenses, especially on cooler surfaces. Very small contents of SO_3 can cause surprisingly high acid dew points. The dew point will be affected by variations in water content of the gas. One part per million of SO_3 will cause an acid dew point of approximately 230°F (110°C). The equilibrium concentration of condensing acid is directly related to the surface temperature and ranges from 50 to 70% at 180°F (82°C) to 80 to 90% at 300°F (149°C).

Chloride and fluoride ions are also present. Under certain conditions and concentrations, chlorides and fluorides can cause severe corrosion of various metals and alloys. Fluorides can react with siliceous materials and may, depending on their concentration, attack some fillers and reinforcements used in linings.

Construction materials, including linings, should be capable of withstanding a variety of corrosive conditions, ranging from acidic (sulfuric/sulfurous) condensation at approximately 130°F (54°C) water saturated, up to high concentrations of sulfuric acid at 250 to 350°F (121 to 177°C). Some flue gas mixing/reheating systems create a spectrum of conditions in between, posing a severe threat to materials of construction.

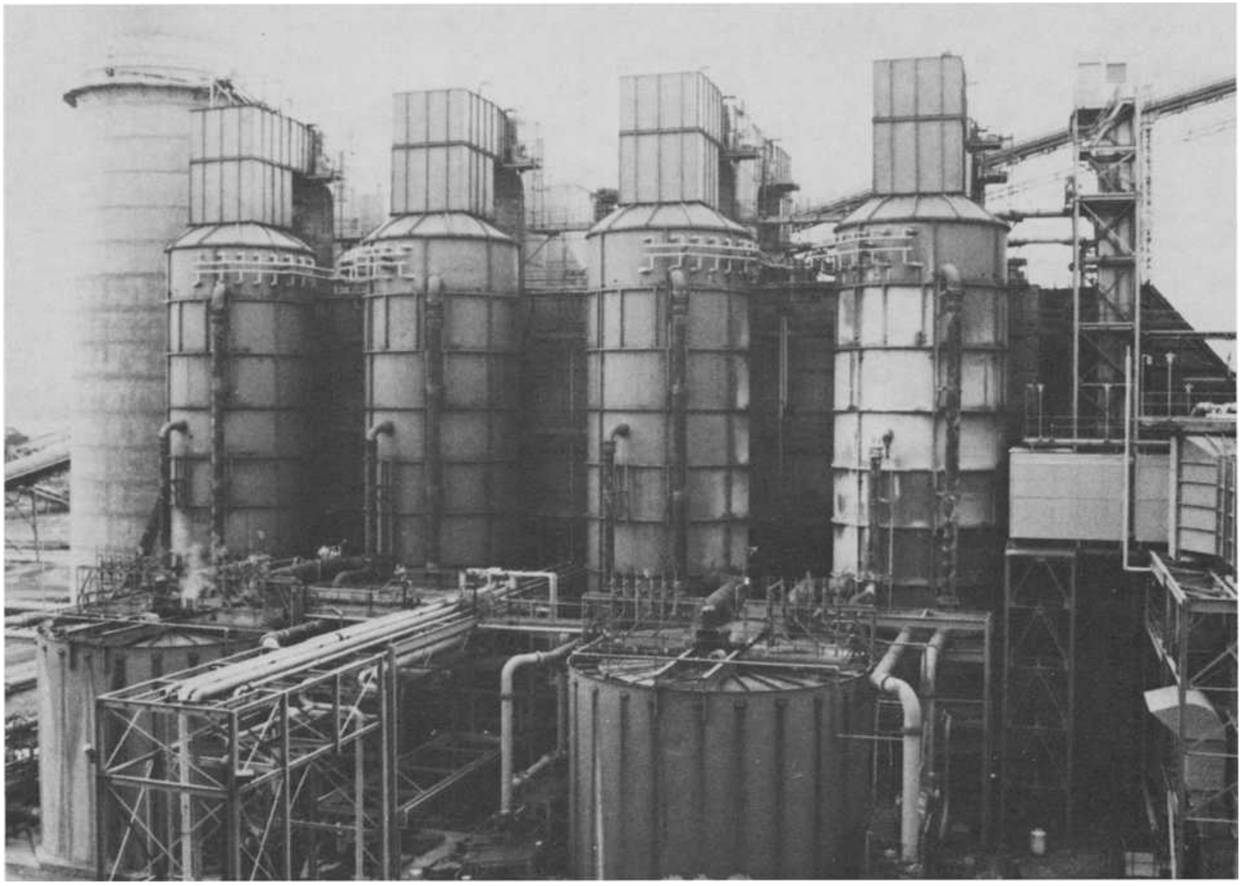

FIG. 1-1—*General view of a limestone FGD system showing four of eight absorber towers. (Photograph courtesy of Stearns-Roger Engineering Corporation.)*

In the event of an air heater failure, flue gas temperatures may rise as high as 700°F (371°C). Safety systems are included to actuate protective dampers, water sprays, and other equipment to prevent linings from being subjected to these temperatures.

Some areas of the FGD system are also subject to severe abrasion because of the velocities of flue gas and slurries used for scrubbing.

Typical Components of FGD Systems

Most FGD systems are fabricated from carbon steel or corrosion-resistant alloys. Typical system components are discussed in the following sections.

Scrubber

The scrubber includes a sump area, an initial contacting area where the flue gas is first contacted by the scrubbing solution, a lower velocity absorption area, and a mist-elimination area.

Ductwork

The ductwork may include the inlet duct in the area of the "wet-dry" interface, the wet (water-saturated) duct from the scrubber, a bypass duct for the unscrubbed gas, and a mixing chamber where either the scrubbed or the bypassed gas or mixtures may flow (Fig. 1-3).

Chimney

The chimney is a free-standing concrete or masonry structure usually with an independent liner of brick, reinforced thermosetting resin (RTR), lined carbon steel, or alloy (Fig. 1-4).

Thickener Tank

The thickener tank is usually a large, very low velocity vessel used to de-water the scrubber effluent solids (Fig. 1-5).

FIG. 1-2—*Absorber towers of FGD system.* (*Photograph courtesy of Ceilcote Company, unit of General Signal.*)

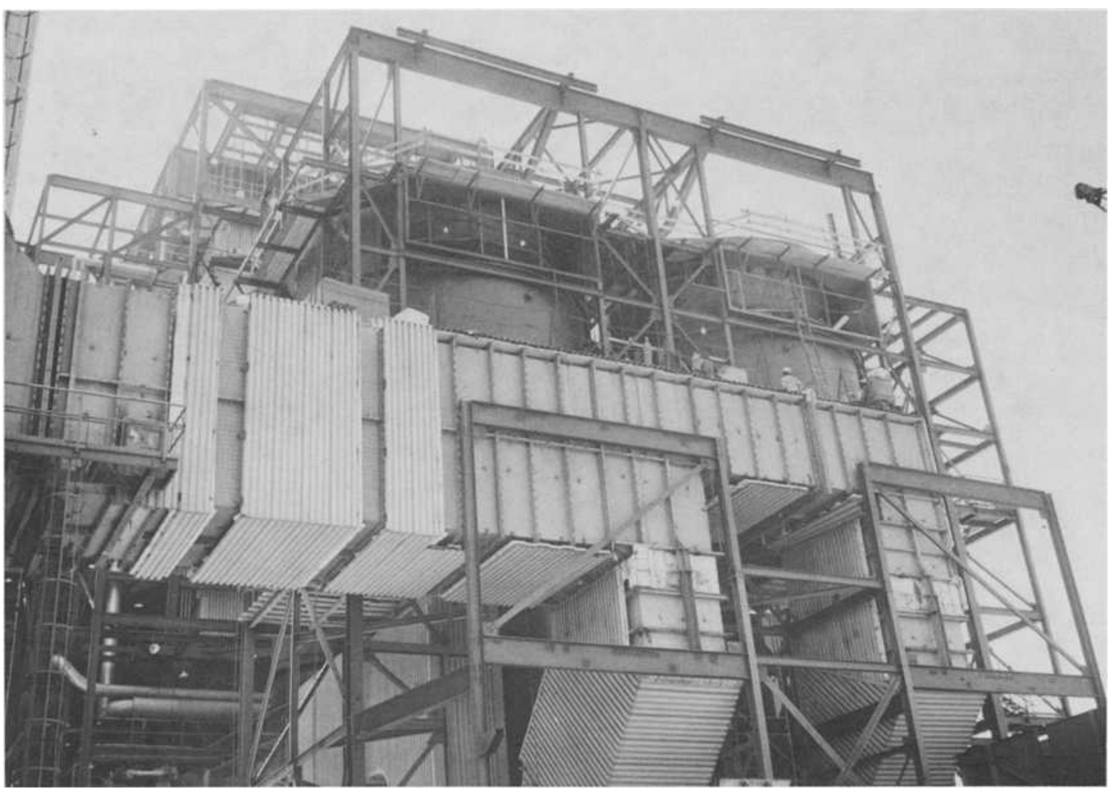

FIG. 1-3—*Typical ductwork from absorbers to chimney.* (*Photograph courtesy of Ceilcote Company, unit of General Signal.*)

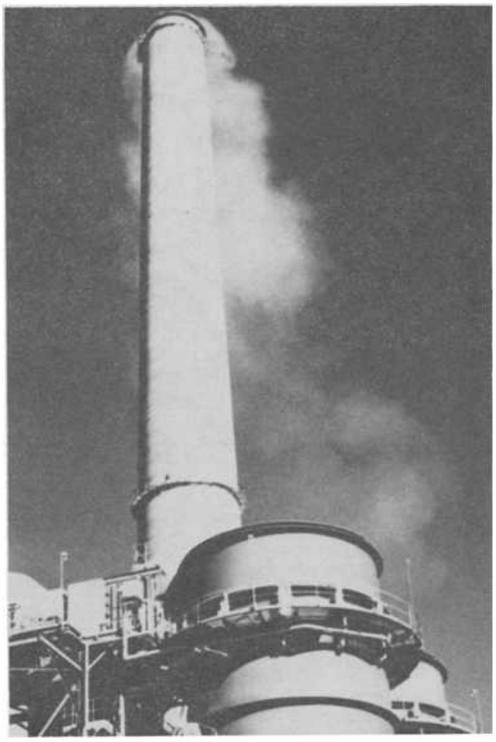

FIG. 1-4—*Chimney on outlet of scrubber system. White plume of water vapor is typical of scrubbed flue gas.* (*Photograph courtesy of Ceilcote Company, unit of General Signal.*)

FIG. 1-5—*Thickener tank for treating effluent from FGD system. This tank has a concrete bottom and steel side walls.* (*Photograph courtesy of Ceilcote Company, unit of General Signal.*)

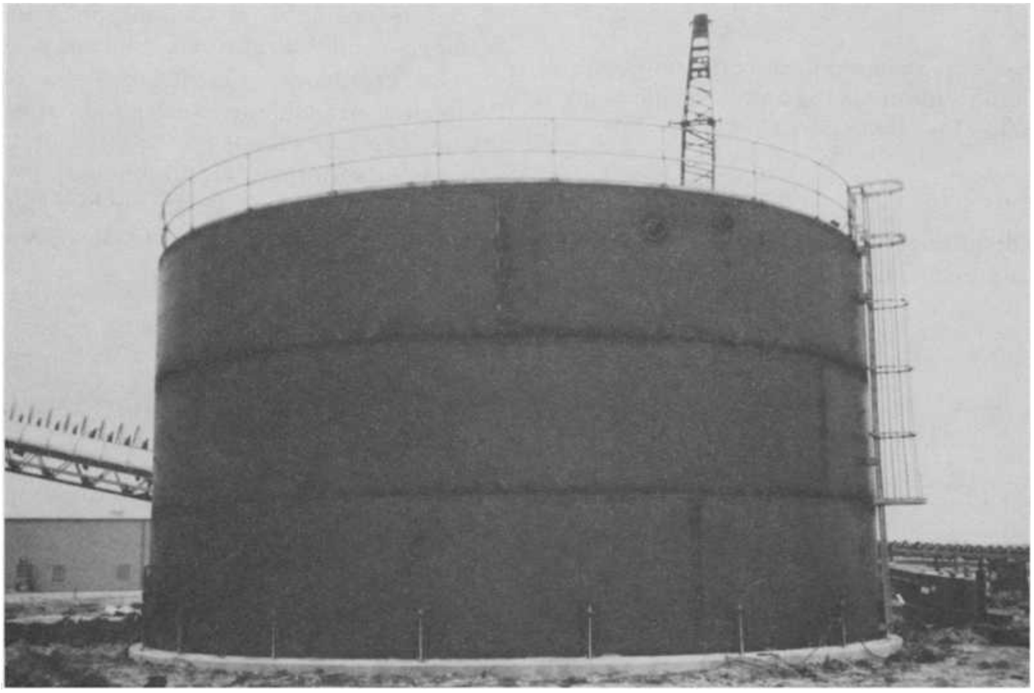

FIG. 1-6—*Auxiliary tank used to prepare, condition, and feed slurry to the absorbers. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

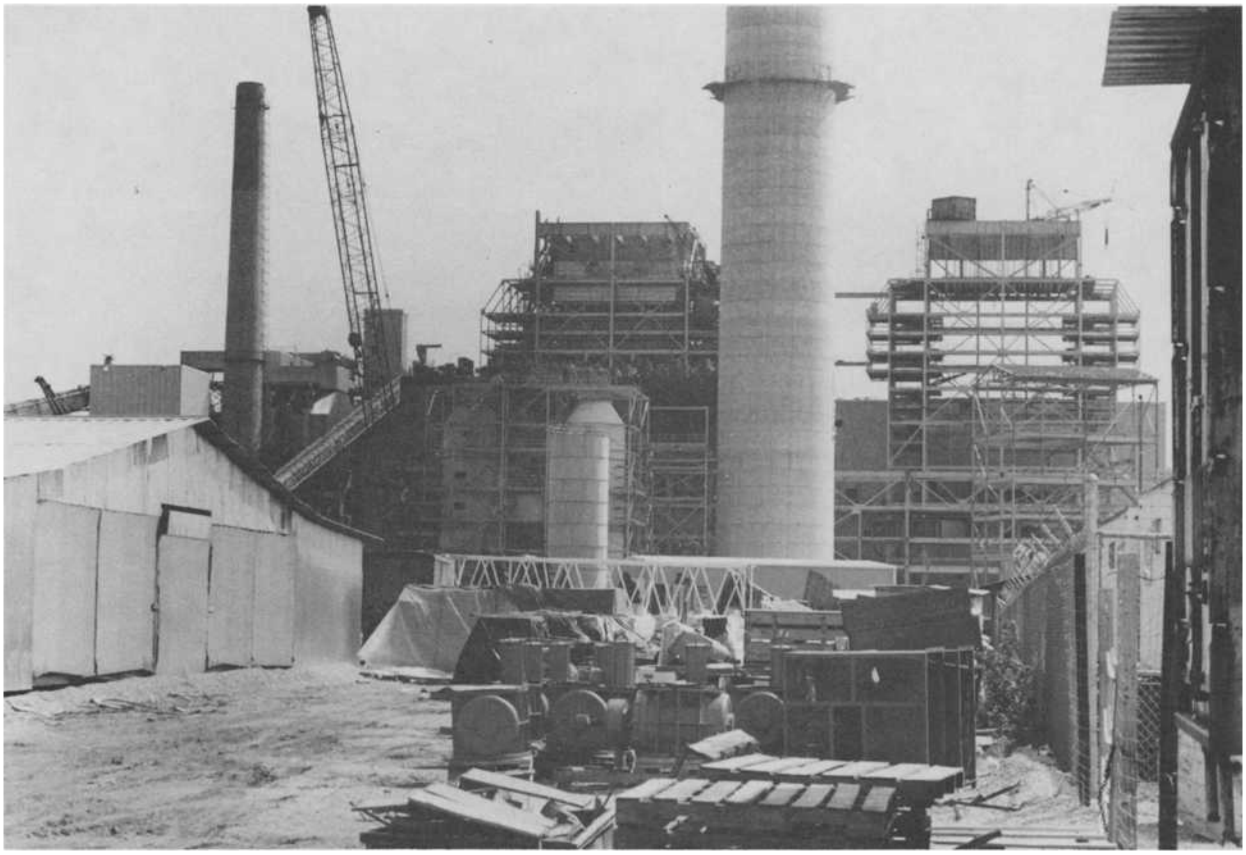

FIG. 1-7—*Typical FGD system under construction. Absorber towers are to the left of the main chimney structure. (Photograph courtesy of Stone and Webster Engineering Corporation.)*

Other Vessels

Other vessels are required to store or condition slurries and solutions for use in the scrubbers, including alkali feed tanks (Fig. 1-6).

State of the Art

Flue gas desulfurization components and processors vary from one manufacturer to another. Because of differences in sources of coal and operational practices, flue gas conditions also vary from one boiler to another. There are many different types of protective lining materials available to protect equipment from corrosion. This manual reflects the present status of protective linings for these wet scrubbing systems and should be used as a guide to understanding and dealing with corrosive conditions in FGD systems (Fig. 1-7).

Chapter 2

Operating and Service Conditions

This chapter defines the operating and service conditions to which linings will be exposed.

Defining Service Conditions

To properly select the optimum lining for an FGD system it is essential to define the service conditions and the effect they may have on the lining. Figure 2-1 is a schematic diagram of a typical FGD system and points out the major zones where linings may be considered. The level of severity of chemical, erosion/abrasion, and temperature for each zone of the system is indicated by a three-digit code characterizing the service conditions. The first digit indicates chemical environment, the second digit indicates abrasion/erosion environment, and the third digit indicates temperature environment.

Owing to the variability in details of design and system configuration, each lining application must be considered individually.

Environmental Severity Levels

The environment in each zone is classified in Fig. 2-1 as to its chemical, erosive, and thermal severity. Three levels are identified, from 1 (mild) to 3 (severe); see Table 2-1.

Chemical Environment

Level 1—pH 3 to 8, the mildest conditions encountered in process slurry. No distinction is made between sulfurous acid (H_2SO_3) and sulfuric acid (H_2SO_4).

Level 2—pH 0.1 to 3, acid concentration up to 15% based on equilibrium concentration of H_2SO_4, water vapor in the gas stream at temperatures above the water dew point.

Level 3—Acid concentration greater than 15%.

Erosion/Abrasion Environment

Level 1—Low-velocity liquid or gas flow.

Level 2—High-velocity gas flow, liquid flow, or liquid sprays.

TABLE 2-1—*Environmental severity levels.*

Level	Chemical	Abrasion/Erosion	Temperature
1	pH 3 to 8; saturated flue gas process slurry; continuous flow or immersion	slow-moving liquids and gases; tank walls	ambient to 140°F (60°C); process slurry
2	pH 0.1 to 3; up to 15% acid concentration; saturated wet gas; acidic liquids; slurries	spray impingement (20 fps or more); strong agitation; spray zones; some tank bottoms and wall areas	140 to 200°F (60 to 93°C); reheated gas
3	acid concentration greater than 15%; intermittent wet/dry zones	high-energy venturi; turning vanes; struts; targets	200 to 330°F (93 to 166°C);[a] inlet gas; bypass gas; reheat gas injection (hot air, fuel fired, inline reheat coil)

[a]Temperatures in the range of 420 to 440°F (216 to 227°C) have been recorded.

Level 3—High-energy liquids or gases carrying particulates.

Temperature Environment

Level 1—Scrubbed, essentially saturated liquid/gas temperatures. Ambient to 140°F (60°C).

Level 2—Reheated gas temperatures: 140 to 200°F (60 to 93°C).

Level 3—Unscrubbed normal flue gas temperatures: 200 to 330°F (93 to 166°C). Temperatures in the range of 420 to 440°F (216 to 227°C) have been recorded.

Other Environmental Factors

Other environmental factors include chlorides, fluorides, oxides of nitrogen, carbon compounds, and synergistic effects.

See Figs. 2-2 to 2-5.

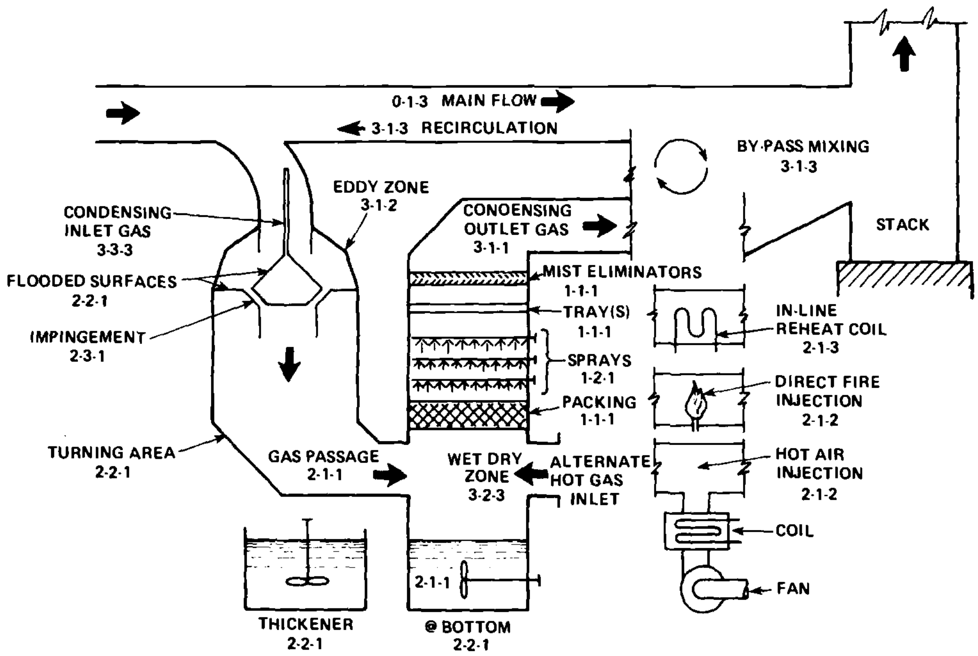

FIG. 2-1—*Schematic of FGD environmental severity levels. This diagram is general and interprets features of several "wet" FGD systems. Three-digit codes denote severity level of chemical-erosion-temperature (see Table 2-1 for description).*

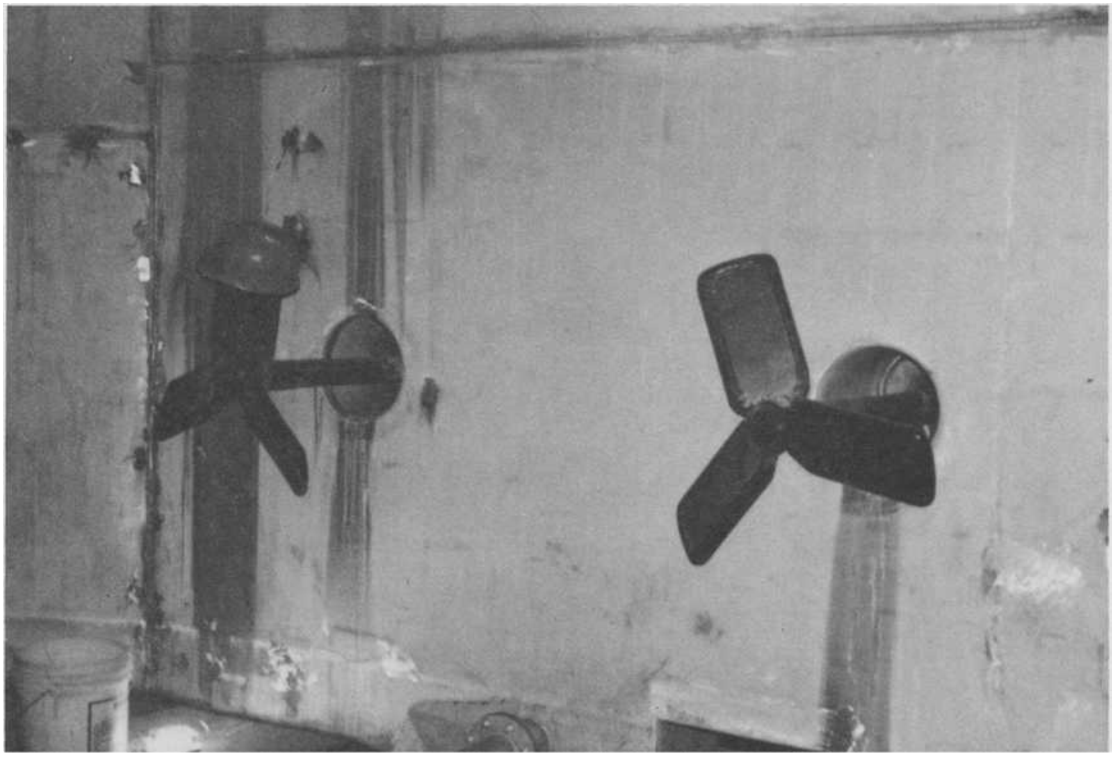

FIG. 2-2—*Sump with agitator blades. Agitator blades and shaft are protected with an elastomer. (Photograph courtesy of Stone and Webster Engineering Corporation.)*

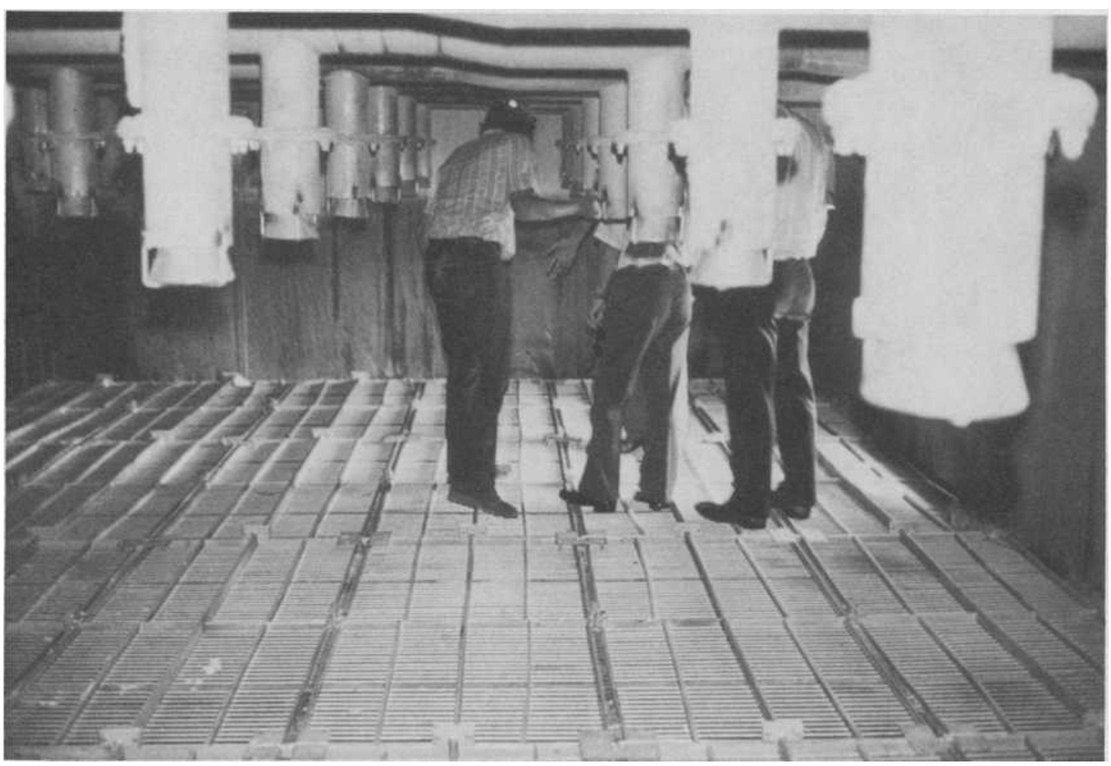

FIG. 2-3—*Spray zone in an absorber. (Photograph courtesy of Stone·and Webster Engineering Corporation.)*

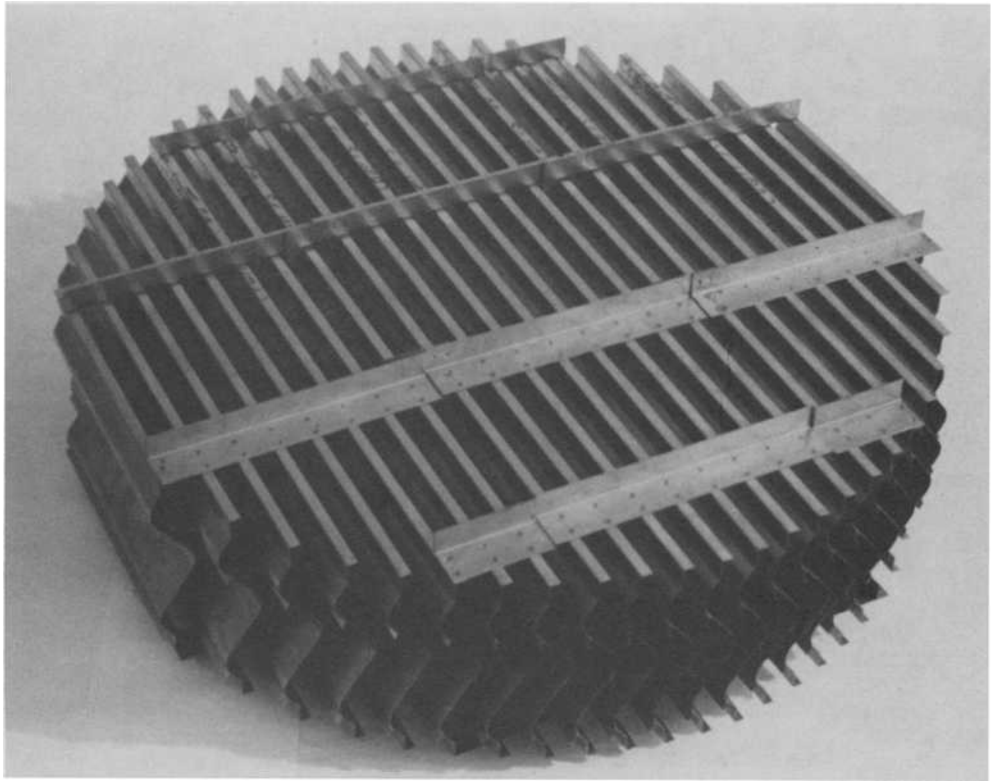

FIG. 2-4—*Section of demister/mist eliminator elements used in FGD system. Typical materials of construction are stainless steel (shown here), fiberglass, and thermal plastics. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

FIG. 2-5—*Typical duct intersection, such as the by-pass duct intersecting the absorber outlet duct. (Photograph courtesy of Stone and Webster Engineering Corporation.)*

Chapter 3

Generic Organic and Inorganic Linings

This chapter characterizes the available lining systems for wet FGD equipment into four generic classes and suggests considerations for selection. The varied chemical, erosive/abrasive, and temperature environments recognized as occurring in FGD systems make it very difficult for any one protective lining system to be able to perform totally satisfactorily in all areas of concern.

Classifications

Organic and inorganic chemical-resistant lining systems are available. These two categories yield the four classes identified and defined below.

Class 1: Organic Resin

Class 1 linings are composed of chemical resinous compounds based on carbon chains or rings, and also contain hydrogen with or without oxygen, nitrogen, and other elements. The formulations incorporate hardening agents to cure the resins and usually fillers or reinforcement to provide desirable physical, thermal, and chemical properties. Application is in liquid form (solution, dispersion, mastic, etc.) using spray, roller, trowel, or other appropriate means (Fig. 3–1).

Class 2: Organic Elastomers

Class 2 linings are based on natural compounds or synthetic polymers which, at room temperature, return rapidly to their approximate initial dimension and shape after substantial deformation and subsequent release. Application is in sheet or liquid form (Fig. 3–2).

Class 3: Inorganic Cementitious Monolithics

Class 3 linings are composed of materials other than hydrocarbons and their derivatives. These protective barriers are comprised of mixtures of chemically inert solid aggregate fillers and a cementing agent. The cementing agent may be an acid-setting compound contained in the fillers and a silicate binder, which harden by chemical reactions, or a high-alumina cement binder contained in the fillers, which hardens by hydration. Application is by trowelling, casting, or pneumatic gun (Fig. 3–3).

Class 4: Inorganic Masonry

Class 4 linings are composed of nonmetallic chemically inert masonry units such as brick or foamed closed-cellular borosilicate glass blocks bonded together with a mortar of adequate adhesion to the units (Figs. 3–4 and 3–5).

Further Information

Owing to the great number of formulation variations by product manufacturers within these classifications, product manufacturers should be contacted directly for further information regarding specific products, their performance, and recommended uses.

Depending on the anticipated service conditions, it may be necessary to consider the application of a combination of chemical-resistant linings, such as an organic lining, as a membrane underneath inorganic monolithic construction or brick/glass block masonry construction. Recommendations on combination considerations should be obtained from lining manufacturers.

Evaluation and Selection Considerations

To provide a specifier with a framework in which to evaluate and select a particular lining system, consideration should be given to the factors in the following sections.

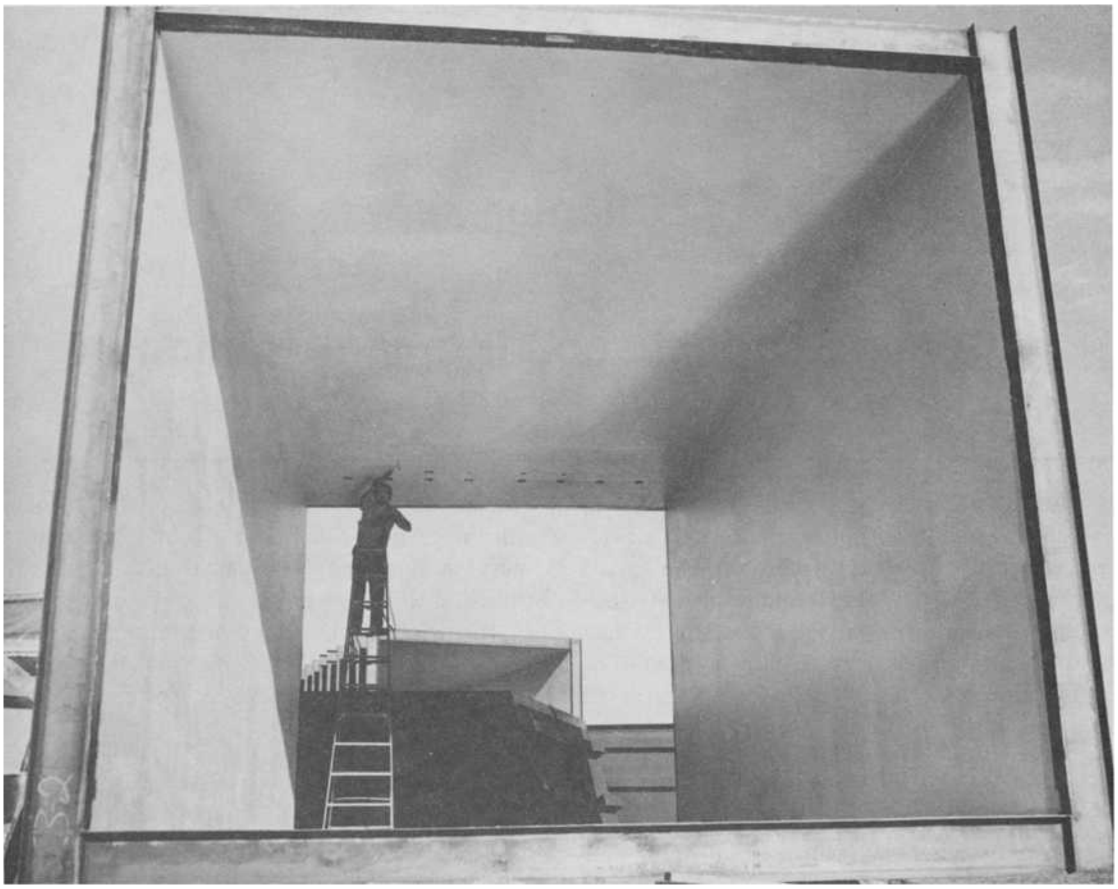

FIG. 3-1—*Organic lining as applied in the field.* (*Photograph courtesy of Ceilcote Company, unit of General Signal.*)

Physical Factors

Physical factors include:

1. Weight of lining.
2. Abrasion resistance.
3. Erosion resistance.
4. Impact resistance.
5. Compressive strength.
6. Tensile strength.
7. Flexural strength.
8. Modulus of elasticity.
9. Anchorage requirements.
10. Adhesion properties.
11. Thickness.
12. Substrate preparation.
13. Substrate installation (temperature/humidity).
14. Shelf-life of lining components.
15. Curing temperatures.
16. Flexibility.
17. Ability to withstand vibration.

Thermal and Chemical Factors

Thermal and chemical factors include:

1. Temperature resistance (high/low).
2. Fire resistance.
3. Chemical resistance (concentration).
4. Thermal shock resistance.
5. Linear coefficient of thermal expansion.
6. Permeability.
7. Absorption.
8. Insulation value.
9. Resistance to varying pH.
10. Maximum continuous service temperature under chemical environment.
11. Maximum dry excursion temperature.
12. Environment external to equipment.
13. Testing in actual or simulated environment.

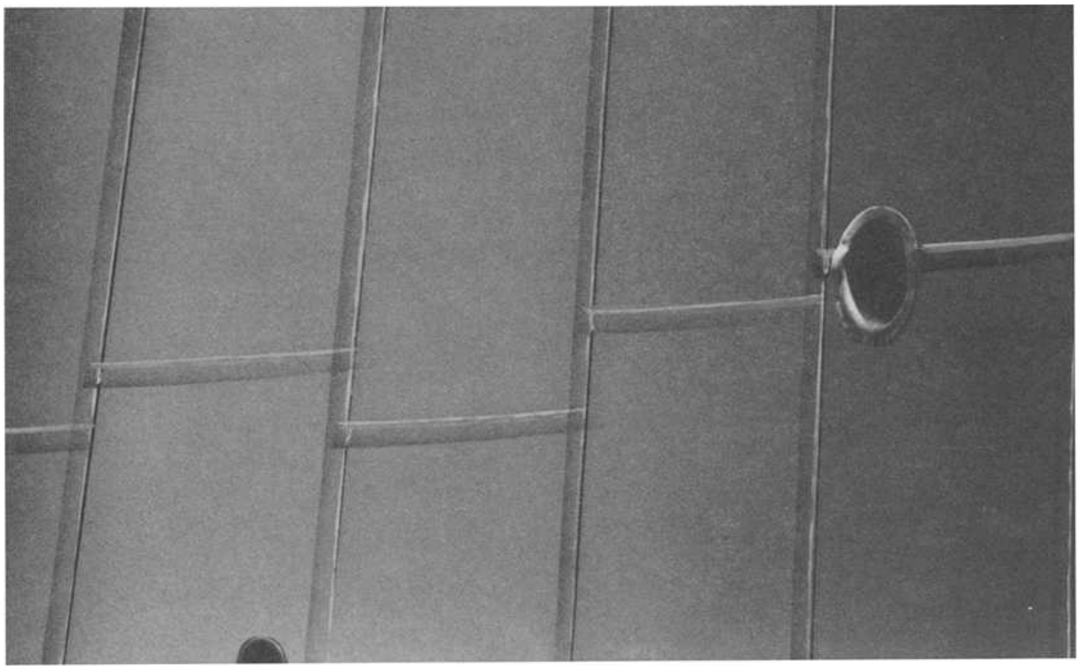

FIG. 3-2—*Sheet rubber lining (organic elastomer) applied to interior tank surfaces. Note overlapped seams and nozzle openings. (Photograph courtesy of Gates Rubber Company.)*

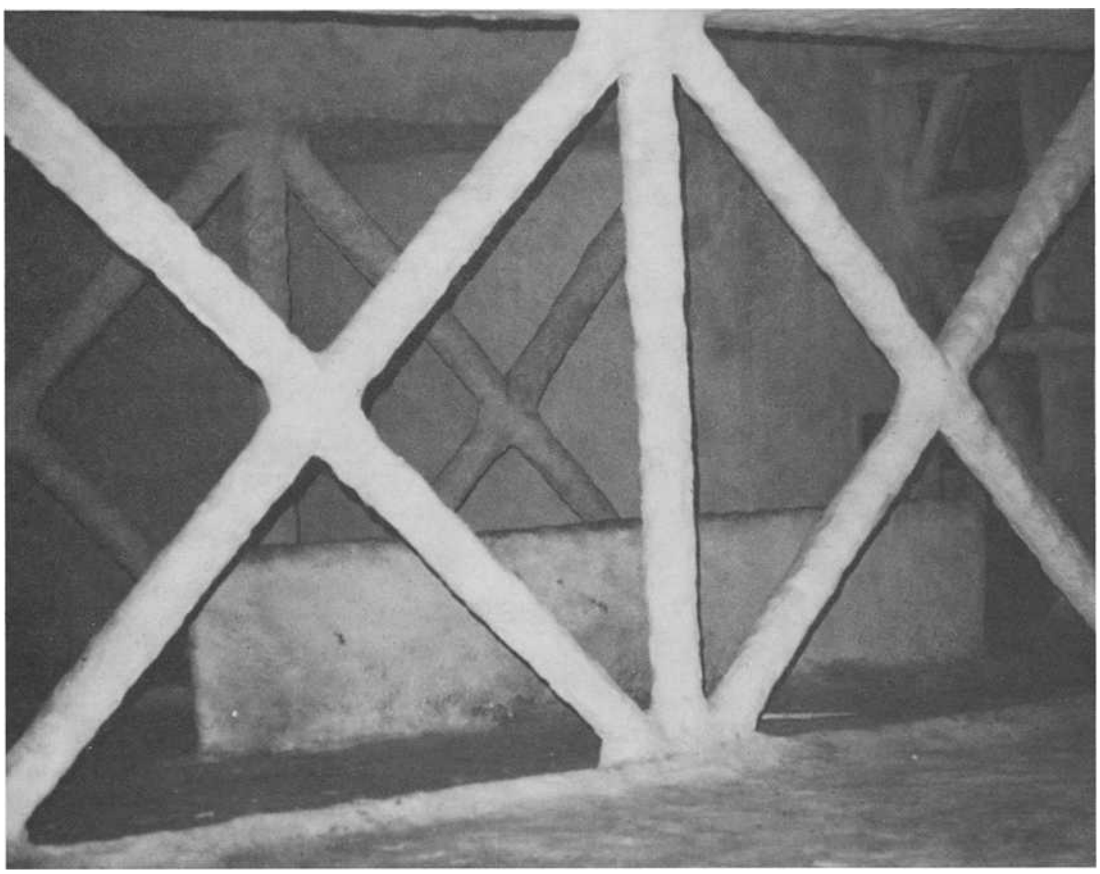

FIG. 3-3—*Inorganic cementitious monolithic lining applied in mixing zone area over complex shapes and surfaces. An organic resin membrane is used under the inorganic material. (Photograph courtesy of Pennwalt Corporation, Corrosion Engineering Division.)*

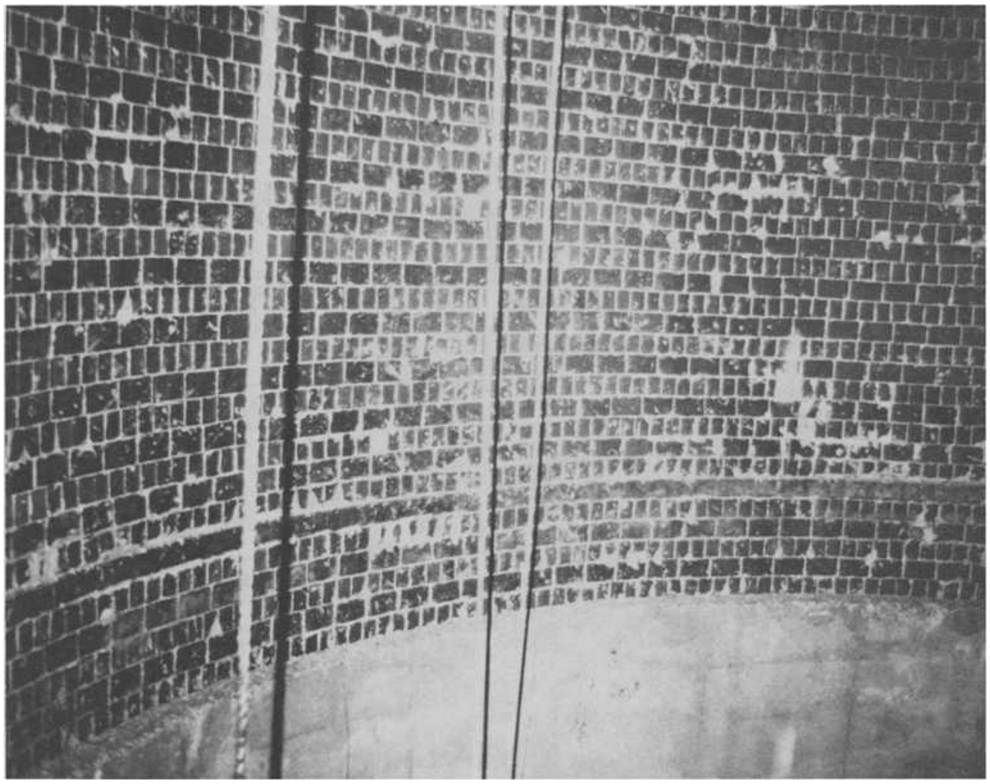

FIG. 3-4—*Masonry lining constructed in a utility chimney. Construction utilizes chemically resistant brick and mortar. (Photograph courtesy of Pennwalt Corporation, Corrosion Engineering Division.)*

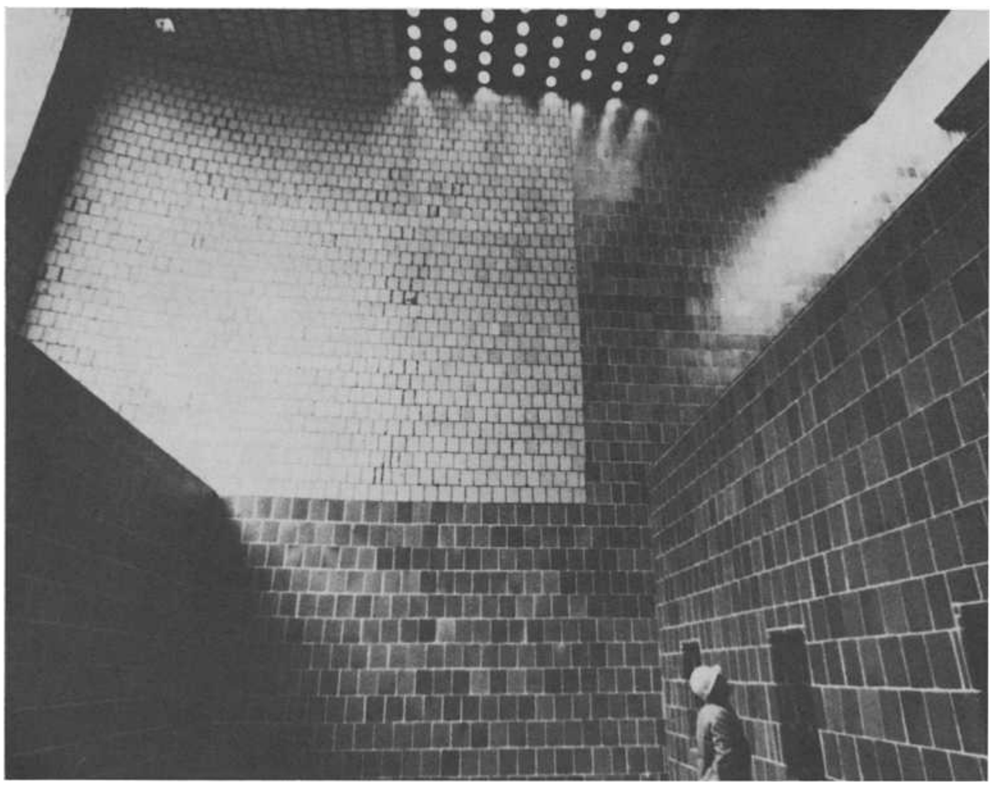

FIG. 3-5—*Chemically resistant masonry construction used in FGD system. Lighter area is acid-resistant brick with furan resin; darker area is acid-resistant tile with vinyl ester resin. (Photograph courtesy of Stebbins Engineering and Manufacturing Company.)*

Operational Factors

Operational factors include:

1. Application
   A. Field storage of lining components.
   B. Impact on schedule.
2. Post-operation
   A. Periodic inspections of lining.
   B. Repairability.

Economic Factors

Economic factors include:

1. Installed cost of lining system per square foot ($\$/ft^2$).
2. Overall cost effectiveness of lining system (structural design, insulation, external coating, etc.).
3. Ease of repair (time and cost).
4. Life expectancy of lining.

Quality Control During Lining Application

Quality control during lining application is a factor that must be considered.

Case Histories

Case histories include:

1. Operating excursions.
2. Chemical, thermal, and erosion/abrasion conditions.
3. Outages.
4. Fuel and flue gas analyses.
5. Length of service of the lining.
6. Frequency and results of lining inspections.

Chapter 4

Design and Fabrication of System Components

This chapter provides guidelines and requirements for the design and fabrication of carbon steel or corrosion-resistant alloy components of SO_2 removal equipment, including scrubbers, tanks, chimney liners, ductwork, and associated equipment that are to be lined for corrosion or abrasion resistance. These criteria pertain to components typically constructed of ASTM A36 carbon steel, but may be used where other steel or corrosion-resistant alloy materials are used for component construction.

Design/Engineering Requirements

Rigidity

The vessel or component should be designed so that the interior metal surfaces are sufficiently rigid for the intended lining material. Lining manufacturers' recommendations for maximum strains or deflection limits for the lining material should be followed.

The weight of the lining system should be considered in the structural design of the component. The design should also consider the effects of pressure, wind, seismicity, and other loads.

Special consideration should be given to all areas of potentially high strain such as unsupported bottom areas, out of roundness, sidewall-to-bottom weld joints, etc. Where the component is on a concrete foundation, grouting may be done to correct unsupported bottom areas. Sand fill may not remain stable and should not be used for bottom support.

Accessibility

Design all interior surfaces of the component to be readily accessible for surface preparation and lining application. Make all fillets and corners accessible for grinding.

The minimum manway diameter for working entrance during lining application should be 24 in. (610 mm). Closed components should have a minimum of two manways, one near the top, and one near the bottom, preferably located 180 deg apart. Additional or larger openings may be required to facilitate ventilation and material handling. Consult the lining material applicator for specific requirements.

Joints

All welds shall be continuous. Intermittent or spot welding shall not be permitted.

Riveted joints shall not be used. Internal bolted joints should not be used except to facilitate installation and to avoid welding on an already lined surface. In these cases, corrosion-resistant alloy or nonmetallic bolts should be used.

Lap-welded joints should be avoided wherever possible. Where lap-welded joints are used, the interior lap should be continuous fillet welded and the edge radius ground.

Expansion Joints/Flanged Joints

Expansion joints and flanged duct or shell joints may require special lining consideration. Flanged joint surfaces should be lined before assembly.

Structural Reinforcement Members (Stiffeners)

If possible, structural reinforcement members should be installed on the vessel exterior. If such members are installed internally, however, they should be fabricated of simple closed shapes such as round bars, pipe, or rounded box beams for ease of applying the lining material.

If closed chambers are formed, they should be vented to the atmosphere at the lowest point, so that (1) pressures are not developed during operation and possible curing procedures, and (2) corrosion due to localized lining failures can be easily observed.

The use of angles, channels, I-beams, and other complex shapes should be avoided. If they must be installed internally, these members must be fully seal welded and the edges ground.

Reinforcement pads and members should be installed externally.

Shell Penetrations

All connections or openings in the vessel or component should be flanged.

The maximum nozzle length of flanged nozzles equal to or greater than 4 in. (100 mm) in diameter should not exceed the dimensions shown in Table 4-1. Use only 4 in. (100 mm) diameter and larger nozzles for maximum reliability. As an alternative to lining, compatible prefabricated, reinforced plastic, or ceramic inserts (sleeves) may be used.

Lining thickness may dictate changes in nozzle dimensions to achieve design flow rates.

Appurtenances Inside Components

All the design/engineering requirements mentioned in this chapter should apply to any item to be installed inside a component to be lined. Such appurtenances include agitators, antiswirl baffles, gaging devices, internal piping, ladders, and support brackets.

If appurtenances inside the component cannot be lined, they should be made of corrosion-resistant materials. If feasible, galvanically incompatible metals should be electrically insulated from each other.

Heating elements should be attached with a minimum clearance of 6 in. (152 mm) from the component surface. Greater clearance may be required to protect the lining from excessive temperature conditions.

Special precautions should be taken in lined tanks containing mixers. Severe abrasion/impingement damage may occur on agitated tank bottoms or walls unless precautionary design measures, such as wear plates or added coating thickness, are specified.

TABLE 4-1—*Maximum length of nozzles.*

Nominal Nozzle Size	Maximum Nozzle Length (Shell to Face of Flange)
4 in. (100 mm)	8 in. (200 mm)
6 in. (150 mm)	12 in. (300 mm)
8 to 24 in. (200 to 600 mm)	16 in. (400 mm)
24 to 36 in. (600 to 900 mm)	24 in. (600 mm)
Over 36 in. (900 mm)	any length

Welds

The degree of weld preparation prior to lining depends on the type of lining to be applied. For liquid-applied and cementitious linings, relatively smooth ripple-finished welds are acceptable. For elastomeric sheet lining, welds should be ground smooth, but not necessarily flush to the parent metal.

Use of weld display samples before and after grinding may help the equipment fabricator to supply acceptable welds with a minimum required rework. Whenever possible, welds shall be inspected in the fabricator's shop.

Surfaces to be lined should contain no gouges, dents, pits, deep scratches, metal stamp marks, "slivered" steel, or other surface flaws which would be detrimental to the lining system. Flaws should be repaired by welding or grinding.

Weld spatter must be removed. Chipping may be used if followed by grinding for finish. (The use of non-silicone, antispatter coating applied adjacent to weld areas is suggested. This coating should be of a type easily removed by the final blast cleaning.)

Pinholes, pits, blind holes, porosity, undercutting, or similar depressions should not exist in the finished surface. Welds should be inspected before and after blast cleaning.

All rough welds should be ground to remove sharp edges. Undercuts and pinholes should be filled with weld metal. Chipping can be used to remove sharp edges if followed by grinding.

All edges and fillets and similar abrupt contours should be rounded off by grinding or machining to a ⅛ in. (3.2 mm) minimum radius. A ¼ in. (6.4 mm) radius at fillets or changes in contours is preferred.

Chapter 5

Suggested Tests for Evaluating Lining Materials

Four classifications of linings are considered here: organic resin, organic elastomeric (liquid and sheet applied), inorganic cementitious monolithic, and inorganic masonry. This chapter suggests tests for providing uniform means for comparing and evaluating various lining materials for use in FGD units. These tests are summarized in Table 5–1. Acceptance criteria are not defined. The proposed tests may or may not be applicable to each zone or environmental severity level. A test that is applicable for one zone may not be applicable to other zones. These tests should not be construed as replacing the need for full-scale testing of lining systems in actual FGD operating units.

These suggested test procedures have been submitted by manufacturers of various types of linings as being useful for determining specific physical properties of these linings. Round-robin testing has not been done by ASTM Committee D-33 on Protective Coating and Lining Work for Power Generation Facilities, and no consensus has been reached regarding the validity, correctness, or correlative value of these test procedures to actual service conditions.

Where a concrete substrate is involved, such as in thickener tanks, the appropriate tests should be run over a concrete substrate instead of a steel substrate.

Conditons within a specific FGD system may affect the performance of a liner system. Some examples might be vibration, fire resistance, concrete crack movement, etc. There exist other tests, both standard and nonstandard, that may be appropriate in addition to the suggested test methods described in this chapter.

Description of Tests

Heat Resistance Test

The heat resistance test determines the maximum continuous temperature which a lining can withstand without undergoing unacceptable deterioration (cracking, blistering, spalling, or loss of adhesion). Test panels heat-aged in accordance with this test may also be preconditioned for other testing such as chemical resistance, tensile strength, and elongation.

The test should be run in an air-circulating oven exposing the lining to continuous dry heat (Fig. 5–1). It is important that the lining system be applied at its maximum recommended thickness to a suitable substrate so that the resulting thermal stresses will be developed. It is suggested that the substrate be carbon steel plate with a minimum size of 8 by 8 by ¼ in. (203 by 203 by 6.4 mm). The effects of this test are expected to be time dependent; six months is suggested as a reasonable exposure time. The test panel should be examined periodically (monthly) for signs of deterioration. Discoloration alone should not be considered a lining failure.

For the different environmental severity levels described in Chapter 2, temperatures of 140, 200, or 330°F (60, 93, or 166°C) may be chosen to simulate the environment. The test is normally run with the panel totally enclosed in the oven. A somewhat different result may be obtained if the test panel constitutes a wall of the oven having a thermal gradient through the lining and substrate panel.

Temperatures higher than those given previously may result for a short duration from air preheater failure.

This test is not applicable to inorganic cementitious monolithic linings, because these linings by their nature can withstand temperatures of 1500°F (816°C) and even higher and thus are not tested at temperatures in the range normally found in FGD units.

Thermal Cycling Resistance Test

The thermal cycling resistance test simulates the cyclical conditions in FGD systems when the lining is exposed to repeated shutdowns and startups and occa-

TABLE 5-1—*Suggested test procedures for linings.*

Properties	Organic Resin	Inorganic Cementitious Monolithic	Organic Elastomeric: Liquid Applied	Organic Elastomeric: Sheet Applied	Inorganic Masonry
Heat resistance	oven test (see text)	not applicable	oven test (see text)	not applicable	oven test for organic mortar only
Thermal cycling resistance	oven cycling (see text)	oven cycling (see text)	oven cycling (see text)	not applicable	oven cycling (for organic mortar see Column 2)
Chemical resistance					
Immersion	NACE TM-01-74	ASTM C 267[a] (modified)	NACE TM-01-74	ASTM D 471	ASTM C 279 (brick) ASTM C 267 (mortar)
Test cell (Atlas/blind flange)	ASTM C 868 NACE TM-01-74	not applicable[b]	ASTM C 868 NACE TM-01-74	ASTM D 3491	not applicable[b]
Abrasion resistance	abrasion test (see text)	no standard[c]	abrasion test (see text)	ASTM D 3389	no standard[c]
Thermal expansion	ASTM D 696[d]	no standard[c]	not applicable	not applicable	no standard[c]
Adhesion	Elcometer test	not applicable	Elcometer test	ASTM D 429	not applicable
Tensile/Elongation	ASTM D 638	Tensile: ASTM C 307 Elongation: N/A[e]	ASTM D 412	ASTM D 412	no standard[c]
Compression strength	not applicable	ASTM C 579[a]	not applicable	not applicable	ASTM C 279 ASTM C 67 (brick) ASTM C 165 (borosilicate glass)
Absorption	not applicable	ASTM C 413[a]	not applicable	ASTM D 471	ASTM C 240 (borosilicate glass) ASTM C 279 (brick)
Hardness	not applicable	not applicable	ASTM D 2240	ASTM D 2240	not applicable

[a] Linings applied by pneumatic gun cannot be prepared per ASTM C 267. Instead, a panel 4 ft by 4 ft by 2.5 in. (1.22 m by 1.22 m by 6.40 cm) thick is made, and after curing is cut in a 2 by 2 ft (0.61 by 0.61 m) section from the center. This section is then cut into the desired shapes.
[b] This test may be applicable for some systems.
[c] No test is available. Refer to text for discussion.
[d] This test may not be applicable to soft materials.
[e] Test only practical for castables, not for pneumatic gun applied linings.

sional air preheater failure. The maximum operating and minimum ambient temperature which can exist at the site may be chosen to simulate the environment. The test for an air preheater failure should be conducted at the maximum upset temperature for a single cycle at a short duration.

The test should be conducted using an air-circulating oven and a cooling device suitable for providing the maximum and minimum temperatures which exist at the site. The lining system should be applied to a suitable substrate at the maximum specified thickness so that the resulting cyclical stresses will be developed. The panel should be exposed in the air-circulating oven at the selected high temperature for 16 h. After removing and cooling to ambient room temperature, the lining should be examined for all changes which are to be recorded. The panel should then be exposed in the cooling device at the selected low temperature for 6 h. Remove and allow the panel to return to ambient room temperature. Examine and record all changes such as loss of gloss, discoloration, cracking, scaling, separation, etc. This procedure completes one cycle. A total of ten cycles should be completed unless a greater number is specified.

Owing to varying service and ambient temperature conditions, the high and low temperature should be defined to simulate the environment. Possible high ranges are 140, 200, or 330°F (60, 93, or 166°C). Possible lower ranges are 70, 40, or −10°F (21, 4, or −23°C).

Tests to simulate air preheater failure should be conducted in a suitable oven. A panel containing the lining system applied at the maximum specified thickness should be placed in the oven preset at the maximum upset temperature for a minimum of 10 min. The panel should then be removed and allowed to cool to ambient room temperature. This constitutes the single cycle required for this test. After cooling the panel to room temperature, examine and record all changes.

Chemical Resistance Tests

Immersion Coupon Test—The immersion coupon test determines the chemical resistance of a lining by immersing it in a corrosive medium. The selection of suitable corrosive media is made difficult by the various acid concentrations and temperatures to which a lining can be exposed in an FGD unit. In addition, it is difficult to simulate the combined effects of several acids (sulfuric, hydrochloric, hydrofluoric, etc.) in addition to contaminants (such as calcium, magnesium, sodium, etc.) which might be present in an FGD system (Fig. 5-2).

This test is designed to screen lining systems for the Atlas cell/blind flange test. Possible test solutions are 1, 15, 20, and 50% sulfuric acid at 100, 140, or 200°F (38, 60, or 93°C). Other solutions or different temperatures may be selected to simulate an FGD environment. The test should be conducted for six months to determine changes such as blistering, cracking, or loss of adhesion.

Atlas Cell/Blind Flange Test—The Atlas cell/blind flange test exposes one side of a coated steel panel to a corrosive medium under conditions similar to those encountered in actual FGD installations and the other to ambient air. Insulating one side of the panel decreases the severity of this test. The corrosive medium can be condensate collected in an operating stack, or solutions described for the immersion coupon test or other solutions. The test temperature is determined by the severity level. Possible temperatures are 100, 140, or 200°F (38, 60, or 93°C). A temperature differential between the external and internal surfaces of the lining causes acceleration of the permeation of the corrosive medium through the lining.

The suggested test here is ASTM Test for Chemical Resistance of Protective Linings (C 868) or NACE Standard TM-01-74. This test may be modified, where applicable, to include analysis of the test medium before and after testing in order to determine changes which take place during the test (normally run for 180 days) (Fig. 5-3). After the test, the panels are air dried at ambient temperature for a minimum of 48 h and reexamined using a spark tester to locate any flaws (test voltage should be provided by the system supplier) (Fig. 5-4).

Abrasion Resistance Test

The abrasion resistance test simulates direct impingement abrasion or erosion of lining materials when exposed to conditions similar to those in a scrubber.

Erosion or high-energy impact impingement of sprayed liquids on the side walls of an absorber venturi, on turning vanes, and on impingement areas can be very severe. Abrasion-resistant materials should be applied locally to minimize these problems.

A direct blast abrasion-resistance test can be used to simulate conditions similar to those in high-energy impact impingement zones of scrubbers, provided that the following variables are considered:

1. A specific description of the blast media, including a specification for the sand or grit used. A slurry may also be used to simulate certain FGD operating conditions. If a slurry is used, its exact composition should be stated.
2. Nozzle-to-panel distance.
3. Rate of usage of abrasive media.
4. Blast pressure at the nozzle.
5. Angle of impingement.
6. Type and size of nozzle.
7. Duration of test.

No relation between this test and service performance can be given or implied. No single test can possibly duplicate all the different kinds of abrasion conditions encountered in scrubbers (particle size, velocity, angle of impingement, etc.). See Fig. 5-5.

There is no existing representative test method. A reference to an abrasive slurry test can be found in ASTM Test for Abrasion-Resistance of Pipeline Coatings (G 6).

Thermal Expansion Test

The thermal expansion test determines the linear coefficient of thermal expansion of a lining.

Since the coefficient of expansion of the lining may not be identical to that of the substrate, operating temperatures may cause thermal strain between the lining and the substrate. The coefficient of expansion can be used to estimate the thermal strain induced. This value should not be used as a measure of high-temperature performance or temperature limits of a lining.

A suggested test for organic resin linings is ASTM Test for Coefficient of Linear Thermal Expansion of Plastics (D 696). See Table 5-1.

Adhesion Test

The adhesion test determines the adhesion of a lining to a properly prepared surface. The lining manufacturer's recommended procedures should be used and noted in the test report. During any adhesion-type testing, the exact mode of failure of each specimen should be noted carefully as a percentage of the total area fractured. In many cases, the failure mode will be cohesive within a layer of the lining system (Fig. 5-6).

Tension and Elongation Tests

The tensile strength and elongation of lining systems are specific measures of these materials at ambient temperatures and are not in themselves indicative of

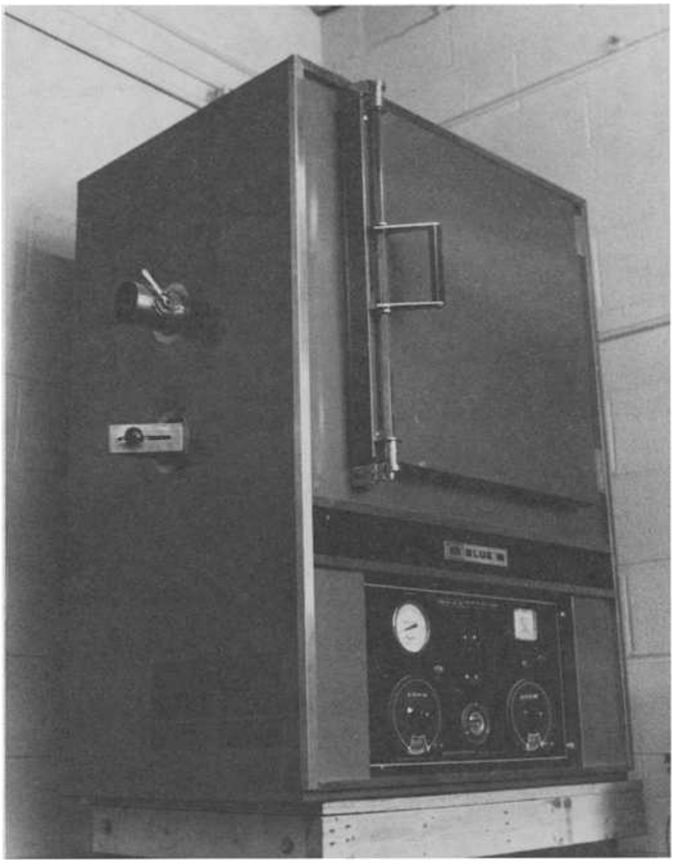

FIG. 5-1—*Oven/muffle furnace for laboratory evaluation of FGD lining materials. High-temperature ovens can be used to evaluate thermal effects on lining materials. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

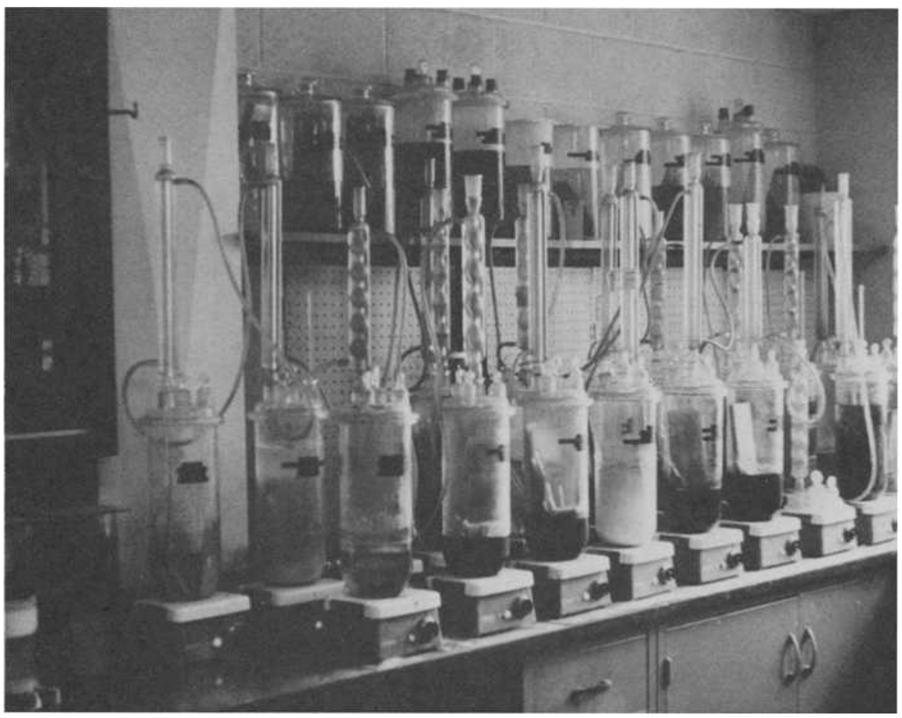

FIG. 5-2—*Laboratory setup for immersion coupon testing of lining materials. These tests are useful for laboratory screening. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

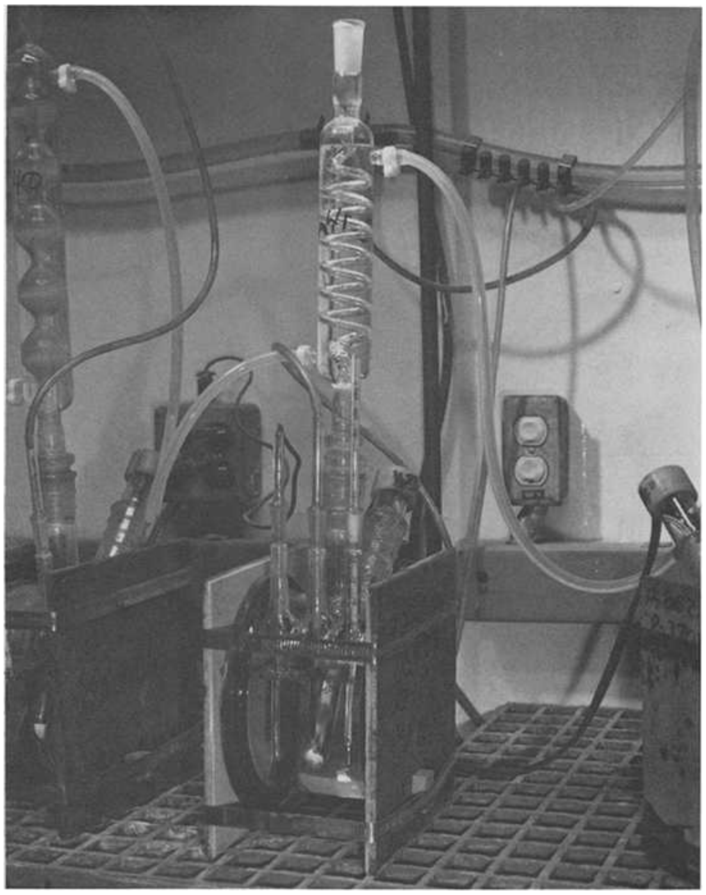

FIG. 5-3—*Testing lining materials using Atlas test cell (ASTM C 868). (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

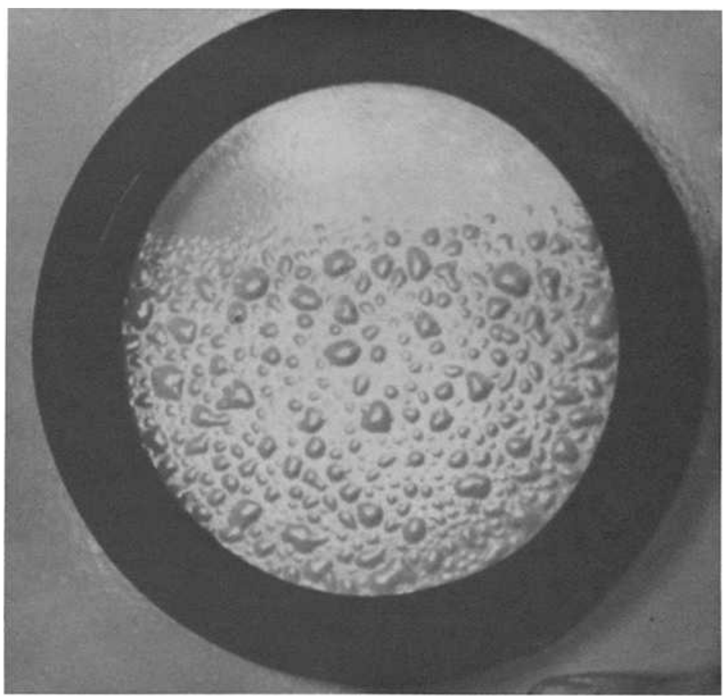

FIG. 5-4—*Test panel after exposure in Atlas test cell. Note severe blistering in liquid phase. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

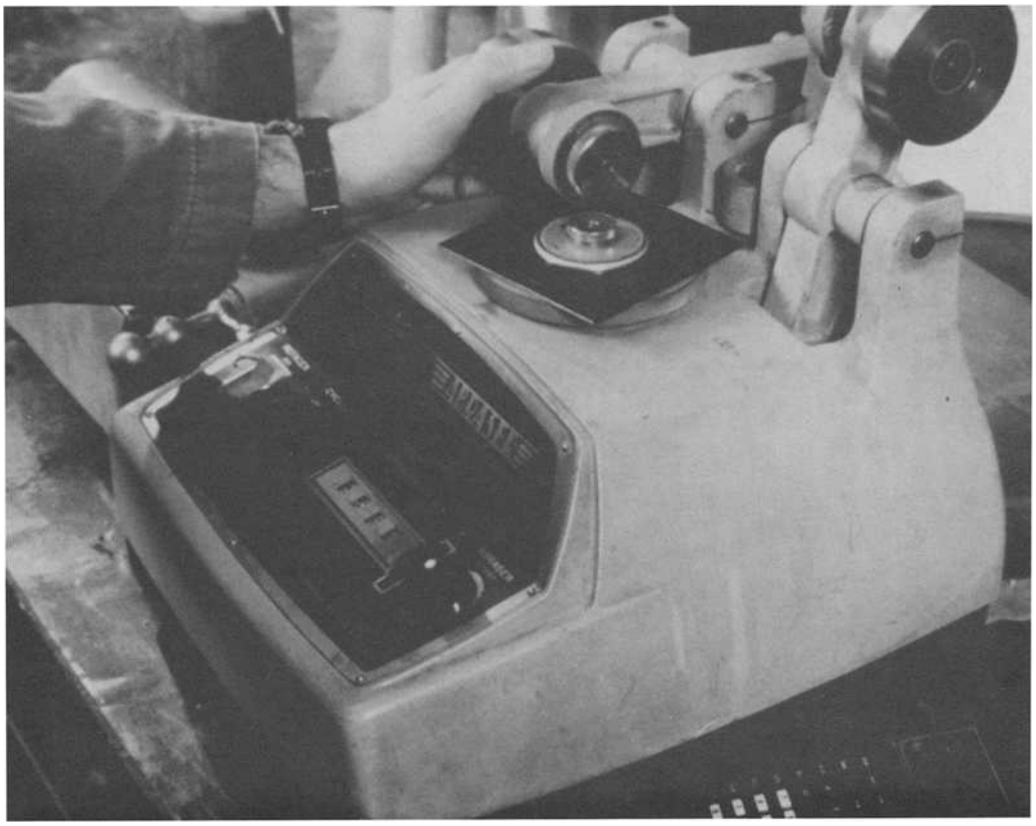

FIG. 5-5—*Abrasion testing using the Taber abraser. This test measures wear of a lining or coating surface under a rolling contact with selected abrasive wheels. It does not correlate particularly well with abrasive liquid or gaseous environments. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

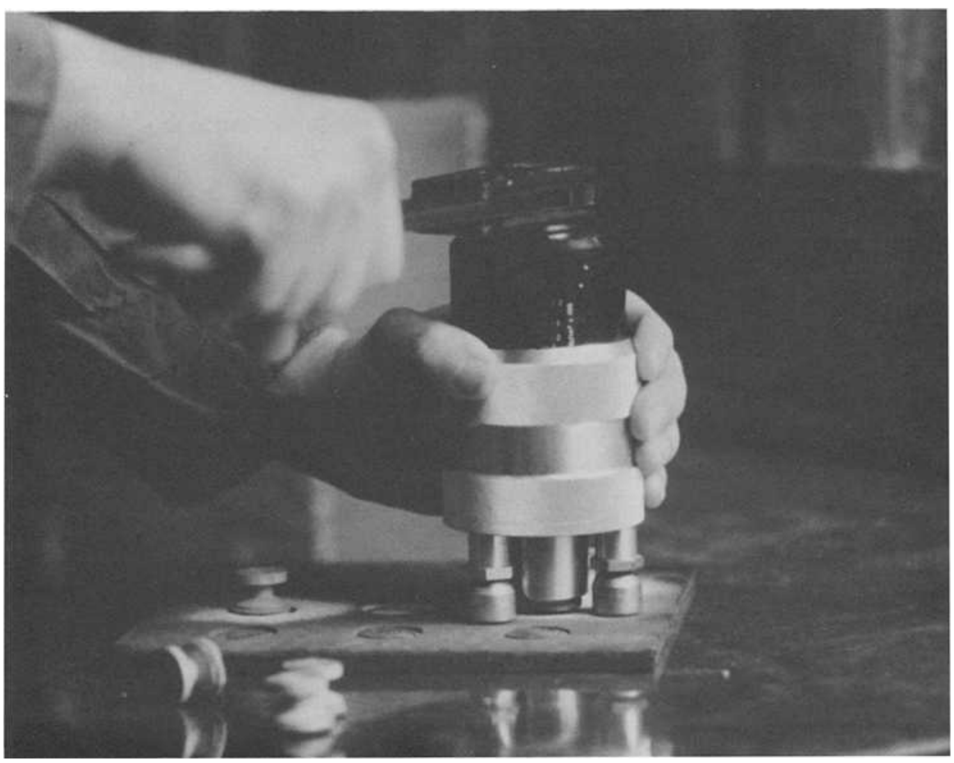

FIG. 5-6—*Elcometer adhesion test. This test uses small aluminum dollies which are adhered to the lining surface and pulled off in direct tension. It is useful since portable equipment is available to perform tests under field conditions. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

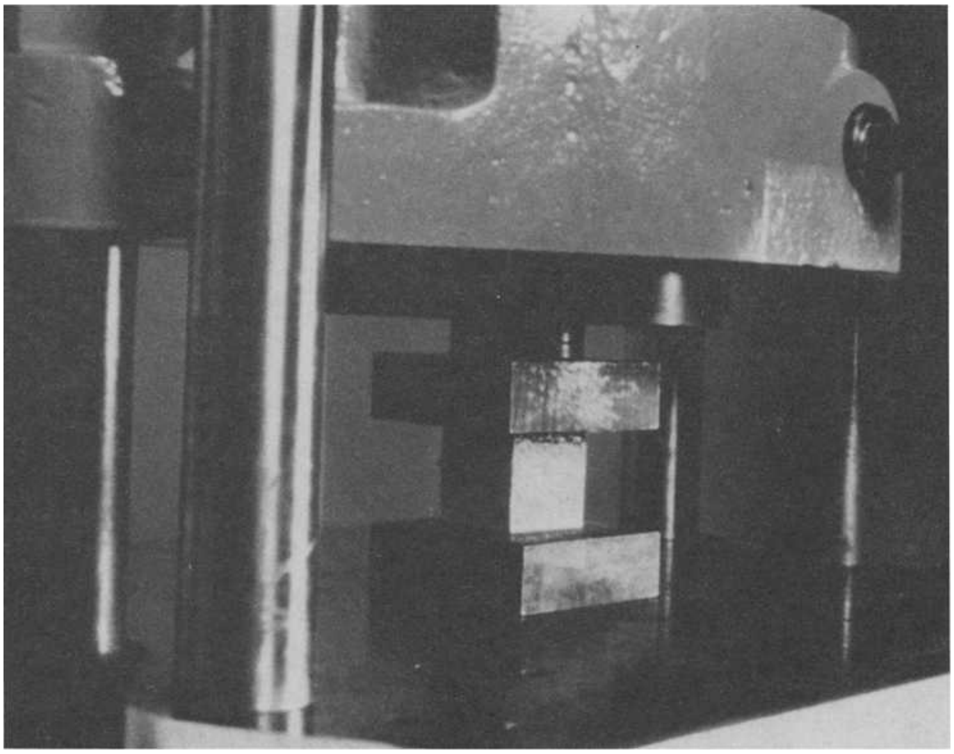

FIG. 5-7—*Compressive strength measured in accordance with ASTM C 579. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

individual lining performance. The tension and elongation tests are run on unbonded lining systems.

Compression Strength Test

The compression strength test applies only to inorganic cementitious monolithic linings and to inorganic masonry (Fig. 5-7).

Absorption Test

The absorption test is applicable only to inorganic cementitious monolithic linings, elastomeric sheet applied linings, and inorganic masonry.

Hardness Test

The hardness test is applicable only to elastomeric linings.

Chapter 6

Lining Material Data

This chapter provides a standardized format for easy comparison of various candidate materials (Figs. 6-1 to 6-3). The tests referenced in this section are described in Chapter 5.

Certain data may not be applicable to a given lining material and should be noted as such on the product data form. When the lining system is composed of more than one product, a product data form should be completed for each product.

PRODUCT IDENTITY

COMPANY DATE:

PRODUCT NAME: PRODUCT NO.:

PRODUCT DESCRIPTION

GENERIC TYPE: ______

GENERAL: ______

MATERIAL SAFETY DATA SHEET (ATTACH)

SURFACE PREPARATION REQUIREMENTS

CLEANLINESS: ______

ANCHOR PROFILE: ______

PREFERRED APPLICATION METHOD (describe, also attach application procedure if appropriate)

APPLICATION CONDITIONS

RELATIVE HUMIDITY:	FROM ______	TO ______
AMBIENT AIR TEMPERATURE:	FROM ______	TO ______
SUBSTRATE TEMPERATURE:	FROM ______	TO ______
MATERIAL TEMPERATURE:	FROM ______	TO ______

CURE TIME PRIOR TO IMPOSING SERVICE CONDITIONS: ______

FIG. 6-1—*Product data form* (*Page one*).

2 PRODUCT NO. ________________

DESCRIBE ANY PREFERRED STARTUP CONDITIONS NEEDED TO OPTIMIZE CURE OR SPECIAL ENVIRONMENTAL CONTROLS AFTER CURE:

NO. OF COATS/LAYERS: ________________ COATING/LINING SEQUENCE: ________

TOTAL DRY FILM THICKNESS ____________ THICKNESS PER COAT/LAYER: ________

INSTALLED WEIGHT OF LINING SYSTEM IN LBS. PER SQ. FT. PROTECTED (including supporting system) AS APPLICABLE:

FLASH POINT: ASTM D93 _______ COLOR: ________________

SHELF LIFE: ________________

STORAGE TEMP. RANGE ________ to ________ °F

FOR LIQUID APPLIED LININGS

THEO. COVERAGE @ 1.0 MIL DFT: ________________

FOR LAY-UP TYPE REINFORCED LININGS:

INDICATE UNIT WEIGHT OF GLASS ROVING OR CLOTH AS FOLLOWS:

TYPE	NO.	OZ./SQ.FT.
WOVEN ROVING		
GLASS CLOTH		

THEO. COVERAGE @ ____ MILS DFT: ________________

PERFORMANCE TESTING

Refer to Chapter 5 for appropriate performance tests.

FIG. 6-2—*Product data form* (*Page two*).

3 PRODUCT NO. ________________

MIXING RECOMMENDATIONS FOR LIQUID APPLIED LININGS

THINNER: ____________________ THINNING %: ______________

POT LIFE: 50°F _______; 70°F _______; 90°F _______

CURE TIME (+):	TOUCH	HANDLE	RECOAT
50°F			
70°F			
90°F			

APPLICATION EQUIPMENT RECOMMENDATIONS

REPAIR PROCEDURE

DESCRIPTION OF PROCEDURE:

FIG. 6-3—*Product data form* (*Page three*).

Chapter 7

Installation

This chapter describes recommendations for the application of protective linings to steel, corrosion-resistant alloys, and concrete surfaces in FGD equipment.

It is the intent of this chapter to define those aspects of the work that most directly affect the performance of lining systems for FGD equipment. These are:

1. Project specifications.
2. Application procedures.
3. Quality control.

These recommendations apply equally to all types of lining systems for FGD equipment, with minor variations appropriate to the specific type.

This chapter does not address the safety requirements for lining application that must be followed during any lining work.

Project Specifications

The project specifications for FGD linings are normally prepared by the owner, architect-engineer, or FGD system manufacturer. Typically, the project specification should include the following items:

1. Process description.
2. Site ambient conditions.
3. Engineering drawings.
4. Support services available at site.
5. Specified lining materials (systems).
6. Technical requirements for surface preparation, application, and inspection of the linings. Stainless steel, nickel-based alloys, and other corrosion-resistant alloys may require special precautions in order to properly secure adhesion to the metal.
7. Minimum quality control requirements.
8. Warranty/guarantee requirements.

Application Procedures

The applicator's work procedures should be based on the project specifications, his own work experience, and the lining manufacturer's application recommendations. The applicator's work should include, but not be limited to, the following elements:

1. Procurement.
2. Receiving of materials.
3. Storage and handling.
4. Prework inspection of substrate.
5. Qualification of procedures and personnel.
6. Surface preparation.
7. Application or installation of lining materials.
8. Cure of lining materials.
9. Repair of lining materials.
10. Maintenance of storage conditions for the completed lining (normally the responsibility of the owner) (Figs. 7-1 to 7-8).

Quality Control

A quality control program should be established as part of the lining application because of the criticality of the lining work required for FGD systems.

The applicator's quality control inspector should function independently from production.

The quality control program is the responsibility of the applicator and should address, as a minimum, the requirements of the project specifications and the approved application procedures. These may include the following elements:

1. Procurement control (material certification to the project specifications).
2. Material receipt inspection (verification of purchase order, recording of lot numbers, noting physical condition of containers or materials).

FIG. 7-1—*Field application of organic linings.* (*Photograph courtesy of Ceilcote Company, unit of General Signal.*)

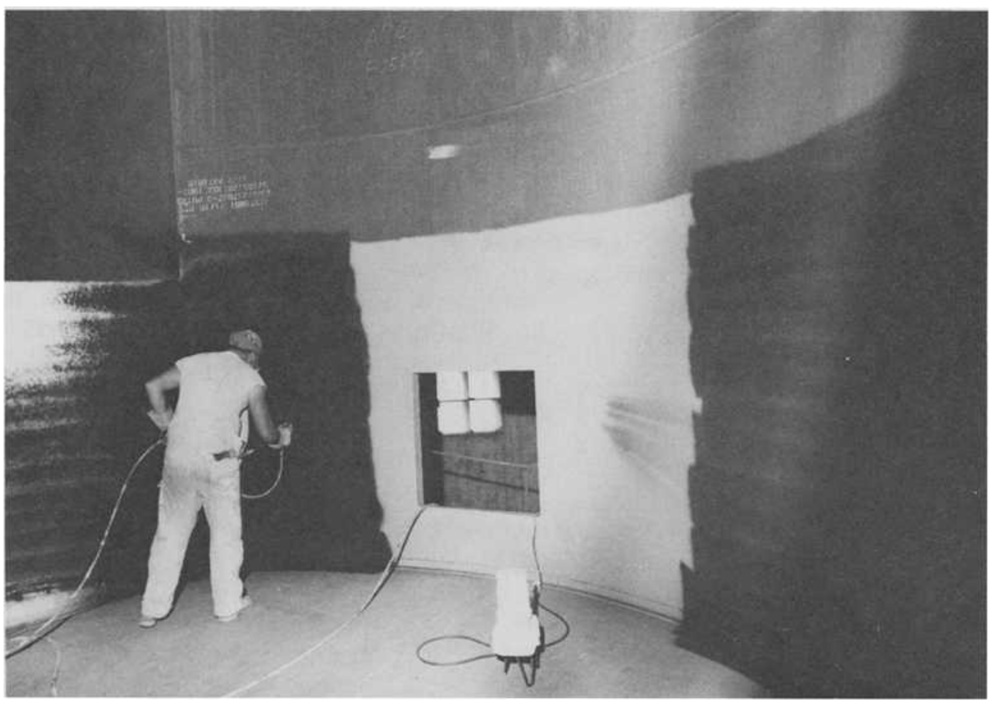

FIG. 7-2—*Application of a liquid-applied fluoroelastomer.* (*Photograph courtesy of Gilbert/Commonwealth.*)

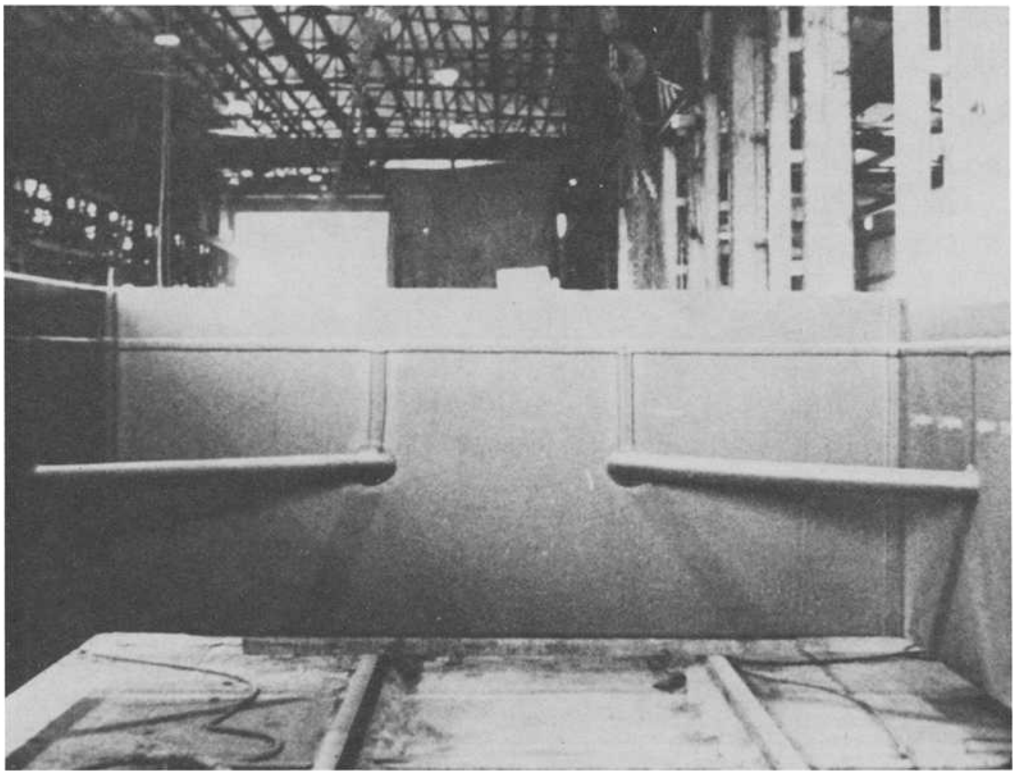

FIG. 7-3—*Modular construction of absorber section lined with sheet-applied elastomer. This is pressure vulcanized before assembly.* (*Photograph courtesy of General Electric Environmental Services.*)

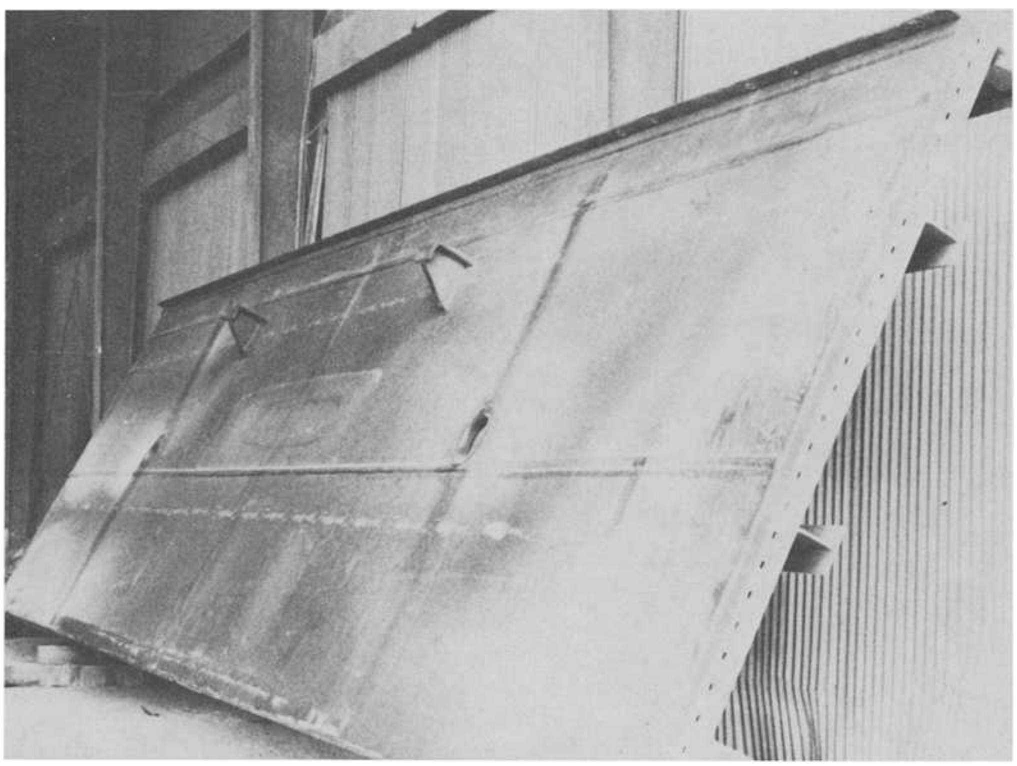

FIG. 7-4—*Panel section for absorber which has been lined with sheet-applied elastomer. This is pressure vulcanized before assembly.* (*Photograph courtesy of General Electric Environmental Services.*)

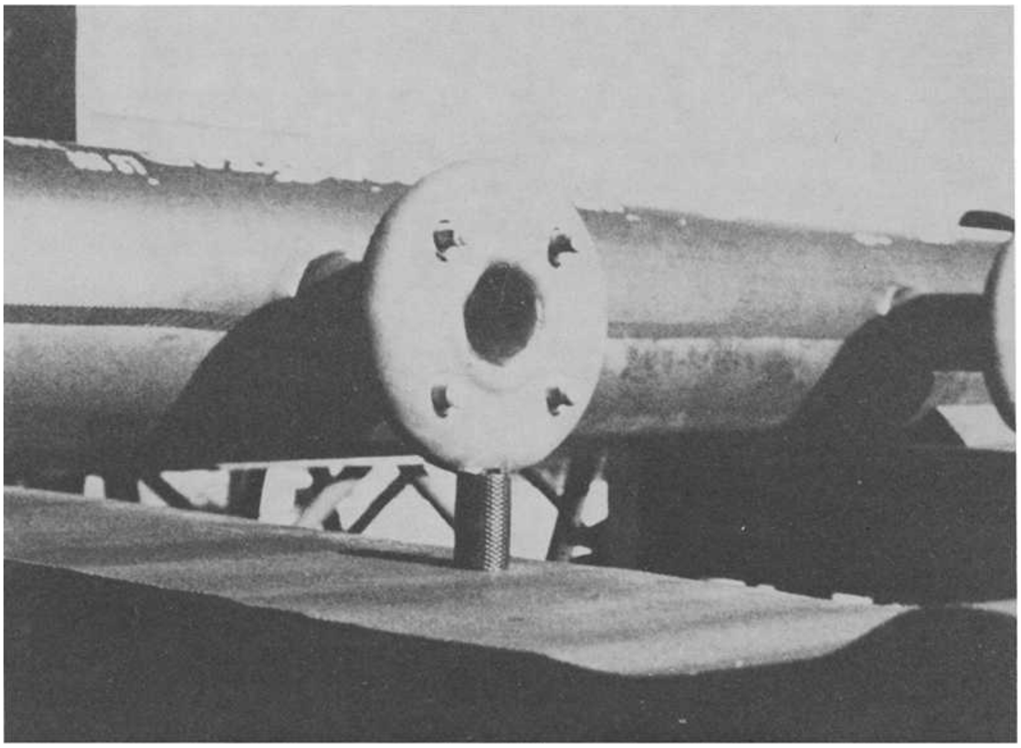

FIG. 7-5—*Sheet elastomer protects absorber header outside diameter. In foreground is an insert to line flange bolt holes.* (*Photograph courtesy of General Electric Environmental Services.*)

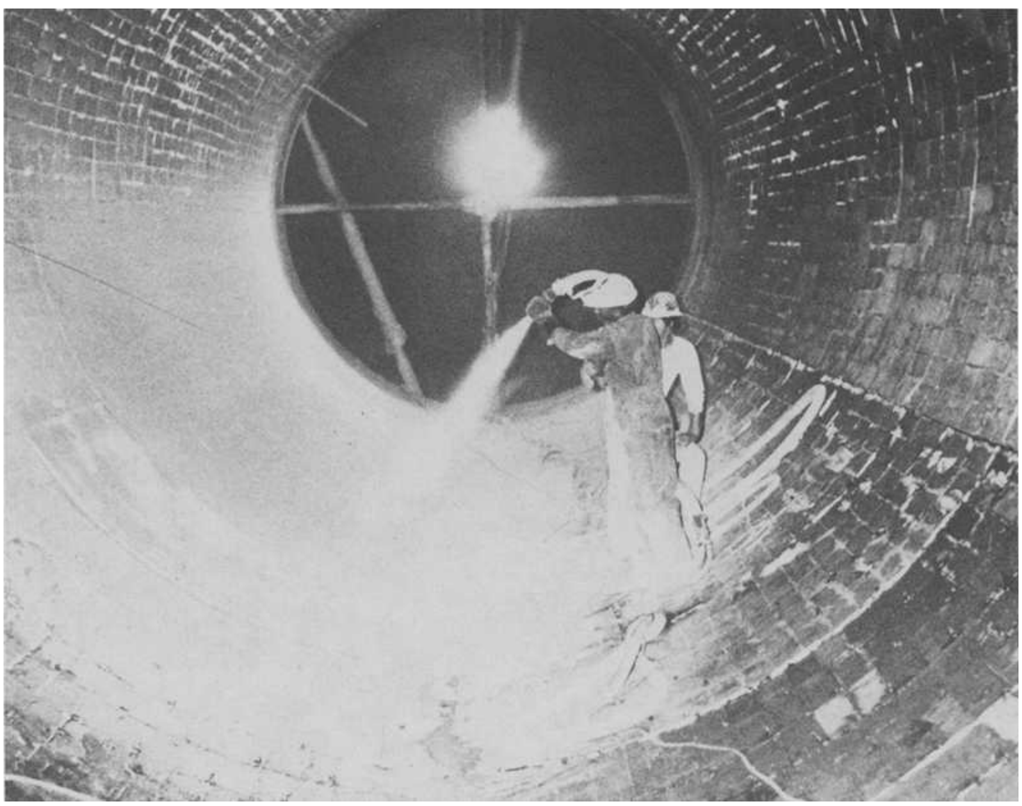

FIG. 7-6—*Field installation of a cementitious monolithic being applied by pneumatic gun.* (*Photograph courtesy of Pennwalt Corporation, Corrosion Engineering Division.*)

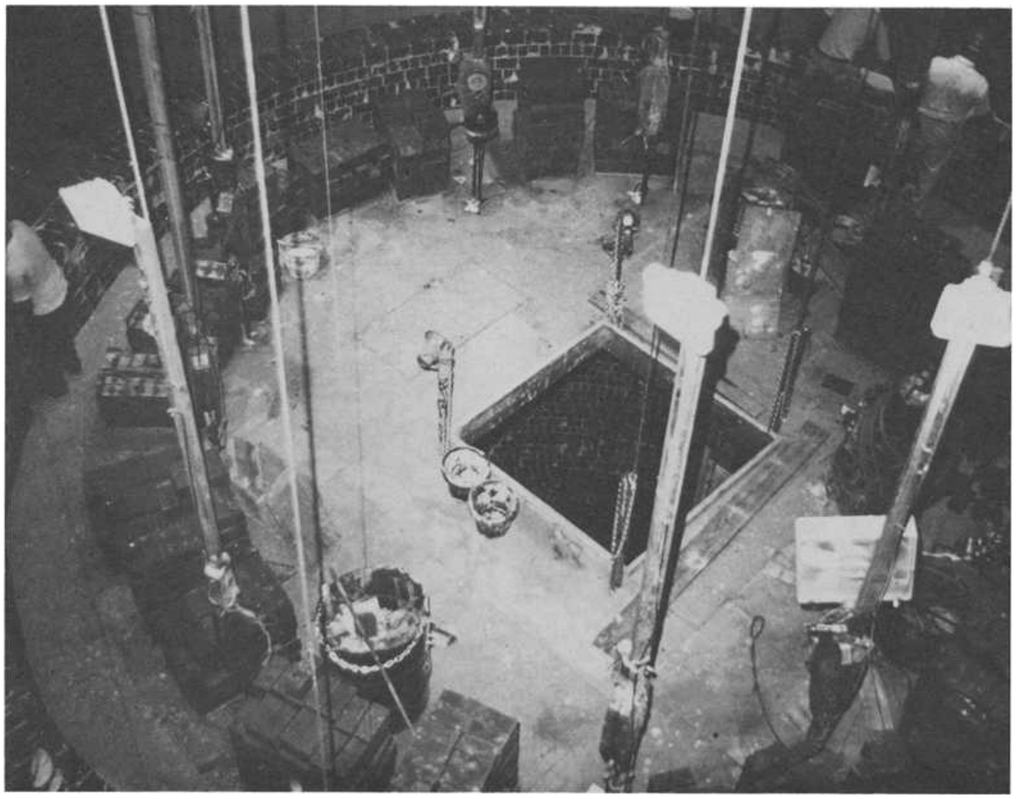

FIG. 7-7—*Construction of an independent masonry lining within a reinforced concrete chimney. (Photograph courtesy of Pennwalt Corporation, Corrosion Engineering Division.)*

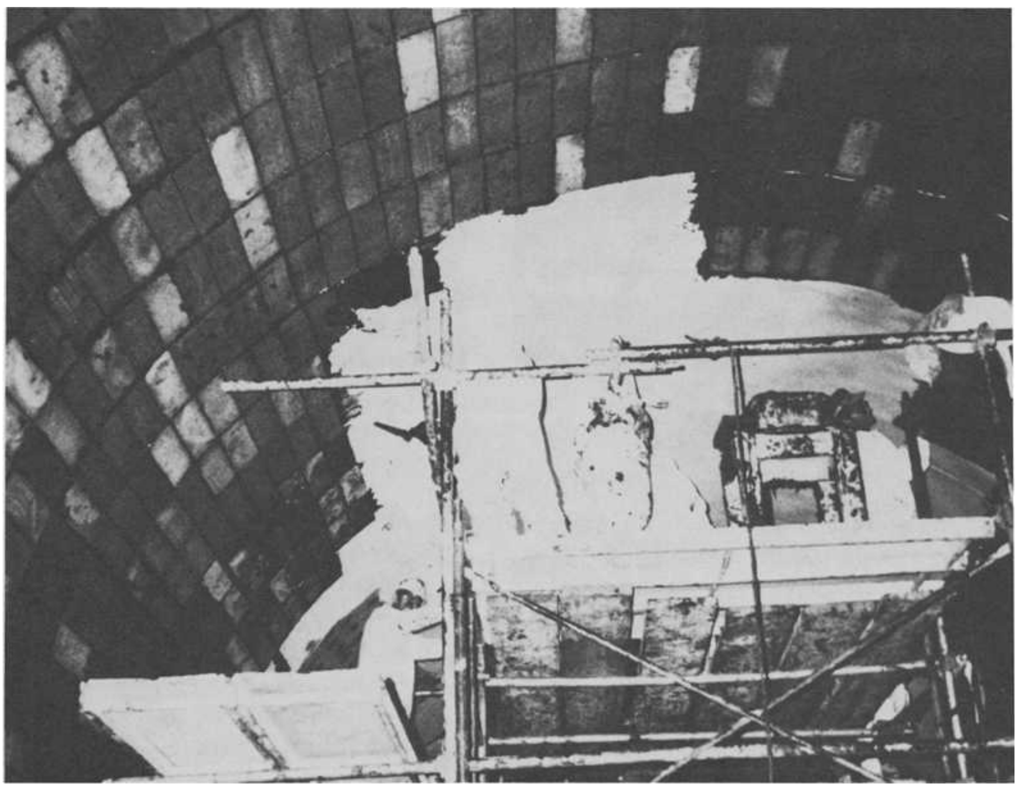

FIG. 7-8—*Masonry lining composed of foamed closed-cellular borosilicate glass block, bonded together, and bonded to the substrate with an elastomer adhesive/membrane. (Photograph courtesy of Pennwalt Corporation, Corrosion Engineering Division.)*

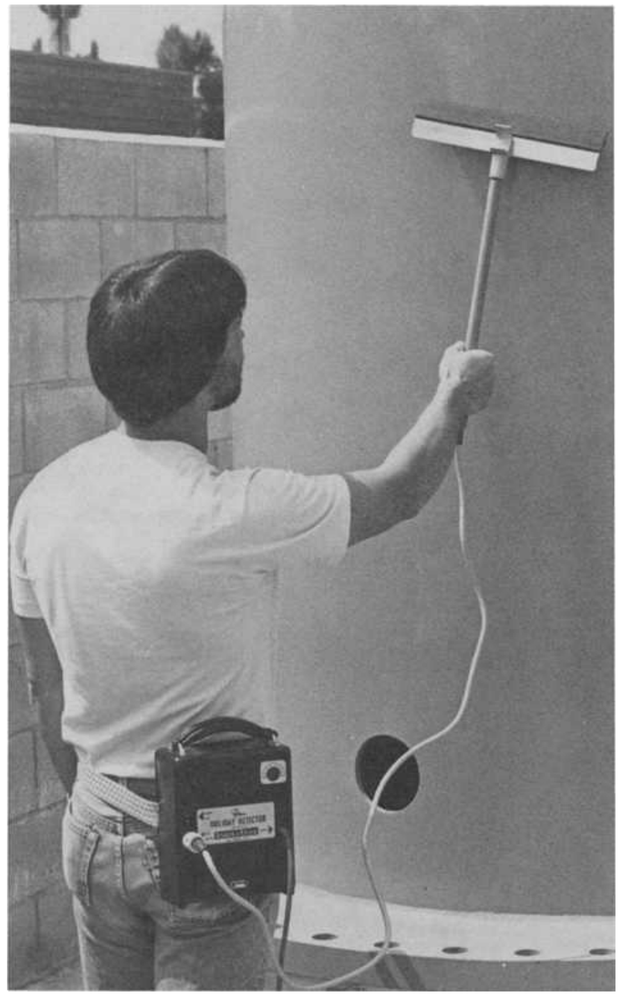

FIG. 7-9 (left) and FIG. 7-10 (right)—*Spark testing of organic linings with up to 20 000 V to ensure that the lining is pinhole free.* (*Photographs courtesy of Ceilcote Company, unit of General Signal, and Tinker and Rasor, respectively.*)

3. Surveillance of storage conditions and handling (environmental conditions).
4. Prework inspection of substrate (weld spatter removal, sharp edges, weld surface condition, surface accessibility, cracks in concrete).
5. Verification of qualification of personnel and procedures.
6. Verification of surface preparation (cleanliness, surface profile, environmental conditions, substrate temperature, equipment supply air cleanliness, abrasive cleanliness).
7. Monitoring the preparation of and application or installation of the lining materials (film thickness, environmental conditions, substrate temperature, dry time, mixing procedures, pot life, equipment supply air cleanliness) (Figs. 7-9 to 7-13).
8. Verification of cure (recording time/temperature of substrate, hardness measurements, solvent-wipe tests).
9. Monitoring of repair procedures.
10. Monitoring of maintenance of storage condi-

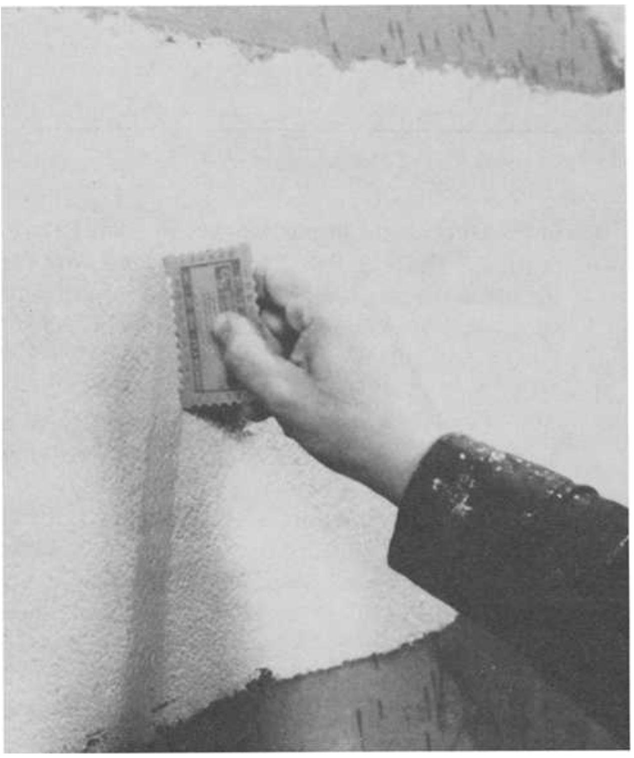

FIG. 7-11—*Wet film thickness testing of a trowel-applied organic lining. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

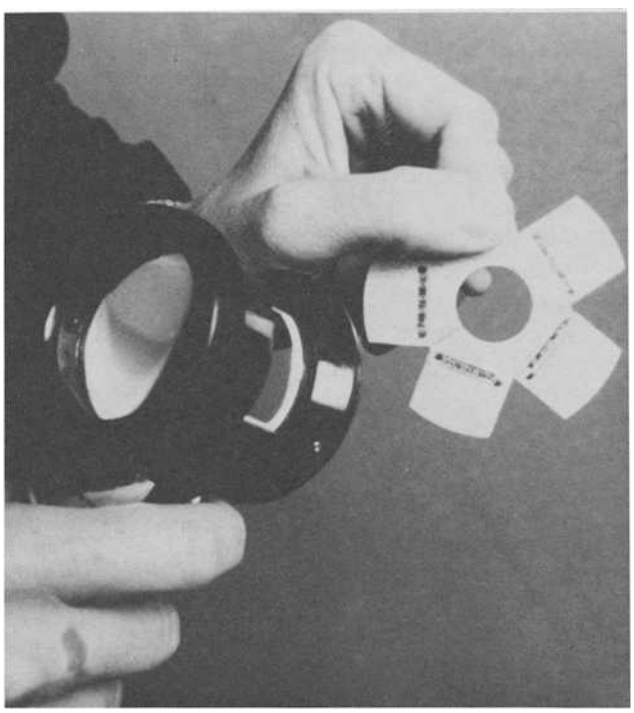

FIG. 7-12—*Keane-Tator surface comparator. A field test determines the depth of profile of a sandblast pattern. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

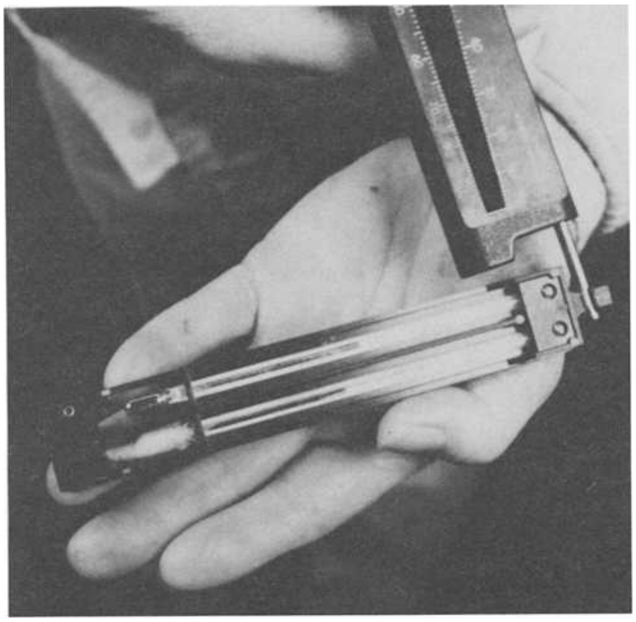

FIG. 7-13—*Sling psychrometer used to measure wet and dry bulb temperature during application of lining materials. This information allows the dewpoint and relative humidity to be determined. (Photograph courtesy of Ceilcote Company, unit of General Signal.)*

tions for the complete lining (normally the responsibility of the owner).

11. Instrumentation calibration and control (maintain list of instruments, assure traceability of calibration history).
12. Reporting and disposition of nonconforming items.
13. Retention and disposition of quality control records.

Additional Recommendations

It is suggested that a prebid conference at the job site be held with all the organizations involved with the specified lining systems to assure that all bidders are fully aware of the job requirements.

A postaward conference should be held at the job site after preparation and approval of application procedures, but before the start of lining work. At this conference, a comprehensive review should be made of all aspects of the job which might adversely affect the lining application.

Bibliography

Berger, D. M., Trewella, R. J., and Wummer, C. J., "Atlas Test Cell Evaluation of Coatings for SO_2 Scrubber Service," *Materials Performance,* Vol. 19, April 1980, pp. 25–28.

Boova, A. A., "Chemical-Resistant Masonry, Flake, and Fabric Reinforced Linings for Pollution Control Equipment," Paper 6, Seminar on Corrosion Problems in Air Pollution Control Equipment, sponsored by APCA, IGCI, and NACE, Atlanta, Ga., Jan. 1978.

Cress, W. R. and Misner, T. L., "Materials of Construction Problems at Pleasants Power Station," Seventh Symposium on Flue Gas Desulfurization, sponsored by EPA and EPRI, Hollywood, Fla., May 1982.

Davidson, L. N. and Gullett, D. E., "Material Selection Consideration for Wet and Dry Flue Gas Desulfurization Systems," Paper 8, Seminar on Solving Corrosion Problems in Air Pollution Control Equipment, sponsored by APCA, IGCI, and NACE, Denver, Colo., Aug. 1981.

Ebner, A. M., "Review of Pleasants Power Station Stack Liner Coating Problems and Their Resolution," Spring Meeting, Pennsylvania Electric Association Power Generation Committee, Marietta, Ohio, May 1980.

Electric Power Research Institute, *Construction Materials for Wet Scrubbers,* Vols. 1 and 2, EPRI CS-1739, Palo Alto, Calif., March 1981.

Electric Power Research Institute, *Literature Review of FGD Construction Materials,* EPRI CS-2533, Palo Alto, Calif., Aug. 1982.

Electric Power Research Institute, *Materials Testing in Simulated Flue Gas Desulfurization Duct Environments,* EPRI CS-2537, Palo Alto, Calif., Aug. 1982.

Engle, J. P., "The Phase Equilibria of the Formation of Sulfuric Acid in Flue Gas," Paper 129, Corrosion/76, NACE, Houston, Tex., March 1976.

Fritz, C. H., "Specifications of Rubber Linings for Wet Scrubbers," Rubber Lining Applications Association Convention, Lafayette, La., Oct. 1982.

Froelich, D. A. and Ware, M. W., "Materials Problem: Operating a Closed-Loop Limestone FGD System," Seventh Symposium on Flue Gas Desulfurization, sponsored by EPA and EPRI, Hollywood, Fla., May 1982.

Haffner, R. F. and Ebner, A. M., "Material Behavior in the Ducts and Chimneys of the Pleasants Power Station," Paper 6, Seminar on Solving Corrosion Problems in Air Pollution Control Equipment, sponsored by APCA, IGCI, and NACE, Denver, Colo., Aug. 1981.

Hendrick, A. L., Wauters, G. B., and Singleton, W. T., "Vinyl Ester Coating for Pollution Control Equipment," Paper 41, Corrosion/79, NACE, Atlanta, Ga., March 1979.

Johnson, C. A., "Evaluation of Materials of Construction for Alabama Electric Cooperative's Limestone FGD System," Paper 4, Seminar on Solving Corrosion Problems in Air Pollution Control Equipment, sponsored by APCA, IGCI, and NACE, Denver, Colo., Aug. 1981.

Katzberger, S. M. and Fang, S. J., "Recent Developments in Materials Selection for FGD Systems," American Power Conference, Chicago, Ill., April 1983.

Koch, G. H. et al, "Experimental Evaluation of Alloys and Linings in Simulated Duct Environments for a Lime/Limestone Scrubber," Paper 197, Corrosion/82, NACE, Houston, Tex., March 1982.

Landrum, R. J., "Designing for Corrosion Resistance of Air Pollution Control Equipment," in *Resolving Corrosion Problems in Air Pollution Control Equipment,* NACE, Houston, Tex., 1976, p. 12.

Lomasney, H. L., "Testing Wet Scrubber Materials," Paper 39, Corrosion/79, NACE, Atlanta, Ga., March 1979.

Pierce, R. R., "Estimating Acid Dew Points in Stack Gases," *Chemical Engineering,* Vol. 84, No. 8, 11 April 1977, pp. 125–128.

Read, G. W., Jr., "Corrosion-Resistant Inorganic Monolithic Linings for Flue Gas Systems," Paper 13, Seminar on Solving Corrosion Problems in Air Pollution Control Equipment, sponsored by APCA, IGCI, and NACE, Denver, Colo., Aug. 1981.

Read, G. W., Jr., and Veater, F. M., "Corrosion-Resistant Linings and Mortars for Incinerators and Chimneys," *Materials Performance,* Vol. 13, No. 3, April 1974, p. 22.

Rung, R. and Patel, U., "Analysis of Operating Experience of Linings in FGD Systems," Paper 3, Seminar on Solving Corrosion Problems in Air Pollution Control Equipment, sponsored by APCA, IGCI, and NACE, Denver, Colo., Aug. 1981.

Sheppard, W. L., Jr., "Using Chemical-Resistant Masonry in Air-Pollution Control Equipment," *Chemical Engineering,* Vol. 85, No. 26, Nov. 1978, p. 203.

Sheppard, W. L., Jr., and McDowell, D. W., Jr., "Controlling Corrosion in Flue Gas Scrubbers: Part 2—Selection and Use of Non-Metallic Materials and Mortars," *Plant Engineering,* March 1979, p. 147.

Singleton, W. T., Jr., "Protective Coatings Formulated from Vinyl Ester Resins for the Air Pollution Industry," Paper 12, Seminar on Corrosion Problems in Air Pollution Control Equipment, sponsored by APCA, IGCI, and NACE, Atlanta, Ga., Jan. 1978.

Skabo, R. R., "A Corrosion Engineer Looks at FGD Systems," Paper 1, Seminar on Solving Corrosion Problems in Air Pollution Control Equipment, sponsored by APCA, IGCI, and NACE, Denver, Colo., Aug. 1981.

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