ABSTRACT

By use of a case history we will attempt to provide the information needed to select and install the materials of construction for the lining of high temperature wet scrubbers using nonmetallic components. The information given herein is drawn from empirical data derived from several recent installations of masonry-lined units that have been evaluated in light of known refractory technology.

INTRODUCTION

Nonmetallic linings can be used in scrubbers for corrosion protection of substrates when the chemical environment is beyond the limit of the corrosion resistance of metals, or when economic considerations make them desirable. It is necessary to select materials in proper combinations and thicknesses for each different chemical exposure and condition of temperature to have a successful lining. There are many types of mortars, membranes, and masonry units available, each having their own particular range of temperature, strength, conductivity and chemical resistance. Within limits, each product has an area of use in which it will perform as well as or better than another.

MATERIAL SELECTION

The selection of an appropriate lining for a high temperature wet venturi scrubber can be exceedingly difficult. With a multiplicity of factors bearing upon the choice of materials, the designer must rely on data available to him from existing linings under similar operating conditions. Data can be obtained from the various manufacturers of acid-resistant mortars. The lining for a particular unit is often determined by a few major conditions that outweigh all the others. The minor conditions usually fall within the context of the overall design.

Material selection is determined by analyzing the design criteria, operating conditions, and the geometric configuration of the unit. In addition, the total system within the scrubber should be evaluated to determine if there are any present and future operating conditions that could be detrimental to the scrubber lining. These include the chemical treatment used in recirculating systems, high temperatures during malfunctions of spray nozzles, and subsequent cold shock by emergency spray systems or other upset conditions or future loadings.

MATERIAL CATEGORIES

FOR ACID RESISTANT SYSTEMS

1. Acid resistant brick or ceramic units.
2. Impervious membranes.
3. Acid resistant mortars.

Acid resistant brick, ceramic fiber, and other ceramic components can generally provide both acid and alkali protection in addition to thermal protection for the various types of membranes. Most brick and mortars are not impervious to chemical penetration as they evidence a measur-
able, though very low porosity. For this reason, vapors, gases and liquids will, in time, penetrate them. In many installations the brick and mortar will help to upgrade borderline membranes by providing a stagnation of the attacking medium on the surface of the membrane. This condition lowers the washing action of the attacking medium, with the result that the stagnated liquid reacts with the membrane. This reacted material then forms a part of the membrane system.

ACID RESISTANT BRICK

There are four types of brick that are predominantly used in corrosion resistant masonry linings for scrubbers: red shale, fireclay, carbon and silicon carbide. Included under this heading is a discussion of Pennguard™ Block.*

REDSHALE BRICK

"Red" Shale Brick is lowest in cost of any of the brick under discussion. It has the lowest rate of absorption and meets ASTM Designation C-279 Type L. This quality brick is used in the cooler zones of the scrubber where thermal spalling is not a concern.

FIRECLAY BRICK

Brick in this group is for use in high temperatures or where thermal shock may be anticipated. Generally this brick is buff in color, meets ASTM Designation C-279 type "H" brick and has a water absorption rate of 5-7 percent.

CARBON BRICK

Comparatively, this is a more expensive brick. It is used in applications where hydrofluoric acid (HF) is encountered, either alone or in a solution containing more than 50 ppm of HF. It is also used in strong caustic environments. Manufacturers of carbon brick provide a special grade for the chemical industry which requires a very low ash content in the range of 4-6 percent for most applications.

SILICON CARBIDE BRICK

Several grades of this brick are available: clay bonded, nitride bonded, oxy-nitride bonded, etc.

They are the most expensive of the brick under discussion. The cost can be twelve times that of clay brick. The choice within the silicon carbide group should be made after consultation with the brick manufacturers. Silicon carbide brick is used where severe abrasion and/or severe thermal shock conditions are anticipated during operation.

PENNGUARD™

In addition to the above brick, there is a new, rigid, lightweight, borosilicate glassblock marketed under the tradename, “Pennguard” by the Pennwalt Corporation of Philadelphia, Pennsylvania. Pennguard™ is now available for use in high temperature wet venturi scrubber linings. This is an impervious material having a temperature limit of 960 F (517 C) with “K” factors ranging below 0.75. It is extremely strong for its weight of 12 lb/ft³ (192 kg/m³). Later in this paper we will demonstrate the advantage that has been added to a system utilizing this material. See Fig. 1 for complete data on Pennguard™ Block.

IMPERVIOUS MEMBRANES

Several classes of membranes are used in scrubber applications. Membranes are selected on the basis of their service temperatures and chemical resistance. These factors vary so widely from product to product that it is of the utmost importance to consult the manufacturer’s tables for chemical resistance and service temperature data. The engineer is cautioned that a material listed to be resistant to several individual components of a mixture, may not necessarily be resistant to the mixture itself. Temperature limits can be different for the same membrane for different chemicals.

NATURAL RUBBER

This is the most common sheet lining used for steel vessels. After it has been applied to the substrate, it must be heat vulcanized either in an autoclave, in the case of a shop installation, or through steam curing for field installations.

SYNTHETIC RUBBERS

Synthetic rubbers like Isobutyl Rubber, Neoprene, Polyisobutylene, Butyl Rubber, Hypalon, etc., are also in use. The advantage of these materials is that they can be field applied in sheet form.
without the need for heat treatment. Some of these synthetic rubbers are also available in liquid form for spray application.

**VINYL MEMBRANES**

Polyvinylchloride (PVC) is a common type membrane which can be field applied using an adhesive system with heat sealed joints.

**RESIN MEMBRANES**

Epoxies, Polyesters, Furans and Polyurethanes are membranes that can be field applied by either spraying or troweling. These generally require glass cloth or glass flake reinforcement.

**ACID RESISTANT MORTARS**

There are two groups of mortars available for scrubber application: silicates and resins.

**SILICATE MORTARS**

Of the various types of silicate mortars available, the ones most commonly used for scrubber applications are of the potassium silicate variety. These are chemically setting cements that provide good chemical resistance to a broad group of chemicals with a pH below 6. They are suitable for use at high temperatures. One silicate mortar presently available has an upper temperature limit of 2500°F (1371°C). Silicate mortars are very susceptible to

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**FIG. 1 TYPICAL PHYSICAL AND CHEMICAL PROPERTIES OF PENNGUARD BLOCK™**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>ENGLISH</th>
<th>METRIC</th>
<th>ASTM TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption of moisture (% by Volume)</td>
<td>0.2 (surface wetting only)</td>
<td>0.2 (surface wetting only)</td>
<td>C-240</td>
</tr>
<tr>
<td>Capillarity</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Combustibility</td>
<td>NON-COMBUSTIBLE</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Composition</td>
<td>Borosilicate glass, totally inorganic, contains no binder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>200 - 210 psi</td>
<td>14.0 - 14.7 kg/cm²</td>
<td>C-165 (hot asphalt capping)</td>
</tr>
<tr>
<td>Density (Standard)</td>
<td>12 pcf</td>
<td>0.19 gm/cm³</td>
<td>C-303</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>90 - 120 psi</td>
<td>5.8 - 7.7 kg/cm²</td>
<td>C-203, C-240</td>
</tr>
<tr>
<td>Linear Coefficient of Thermal Expansion</td>
<td>$1.6 \times 10^{-6}/°F$</td>
<td>$2.8 \times 10^{-6}/°C$</td>
<td></td>
</tr>
<tr>
<td>Maximum Service Temperature</td>
<td>960°F (unloaded)</td>
<td>517°C (unloaded)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>800°F (with applied load)</td>
<td>425°C (with applied load)</td>
<td></td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>180,000 psi</td>
<td>12,600 kg/cm²</td>
<td></td>
</tr>
<tr>
<td>Specific Heat</td>
<td>0.2 BTU/lb./°F</td>
<td>0.2 Kcal/kg/°C</td>
<td></td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td></td>
<td></td>
<td>C-117, C-518</td>
</tr>
<tr>
<td>@ 100°F - 38°C (mean)</td>
<td>0.58 BTU - in/hr. ft²°F</td>
<td>0.073 Kcal/hr. m²°C</td>
<td></td>
</tr>
<tr>
<td>@ 200°F - 93°C (mean)</td>
<td>0.64 BTU - in/hr. ft²°F</td>
<td>0.081 Kcal/hr. m²°C</td>
<td></td>
</tr>
<tr>
<td>@ 300°F - 149°C (mean)</td>
<td>0.69 BTU - in/hr. ft²°F</td>
<td>0.087 Kcal/hr. m²°C</td>
<td></td>
</tr>
<tr>
<td>@ 400°F - 204°C (mean)</td>
<td>0.75 BTU - in/hr. ft²°F</td>
<td>0.094 Kcal/hr. m²°C</td>
<td></td>
</tr>
<tr>
<td>Water-Vapor Permeability</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>
deterioration by water and alkalies. Potable water should never be introduced into a vessel lined with a brick system using silicate mortars, unless the lining has been previously exposed to/or treated with acid and then never for prolonged periods.

RESIN MORTARS

The resins included in this group are the Furans and Modified Phenolics. Compared to the silicate mortars, they have a much lower temperature limit. There is one modified carbon-filled furan available that has a continuous service temperature of 428°F (220°C), otherwise they are limited to about 356°F (180°C). The resin mortars excel in resistance to water and a broad spectrum of acids and are highly resistant to alkalies. They provide good bonding strength and there are some available that expand on curing. This latter property is of particular value when prestressing of brickwork in large vessels is required or when prestressing is needed to offset the forces of vibration sometimes found in Venturi type scrubbers.

DESIGN CRITERIA

The design criteria for scrubber lining material selection is:
1. Configuration and dimensions of unit.
2. Inlet gas temperature.
3. Chemical analysis of gas stream.
4. Concentrations of chemicals involved.
   (Including trace amounts.)
5. Quenching medium.
6. Quenching medium treatment and/or is it recirculated?
7. Outlet temperature of unit.
8. Periodic or continuous service.
9. Type of substrate.
10. Cleaning procedures and cleaning chemicals.

We list below the actual criteria information involved in our case history scrubber to be used in conjunction with a sludge burner in a municipal sewage treatment plant.
1. Proposed design sketch.
2. 1100 F (593 C)
5. Recirculated water.
7. 200 F (93 C)
8. Continuous (shutdown over weekends).
10. No special cleaning procedure required.

The proposed lining as shown on the preliminary sketch indicates a ¾ in. (6.4 mm) natural rubber membrane with 4½ in. (114 mm) thickness of Fireclay Type H Acid Brick, laid up in a carbon filled furan mortar as the service lining. Item Three of our design criteria shows a gas inlet temperature of 1100 F (593 C). A thermal calculation is required to determine the temperature at the rubber lining.

FIG. 2 INITIAL THERMAL (See Chart 1, Part A)

<table>
<thead>
<tr>
<th>Lining</th>
<th>K-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>4½ in. (114 mm) Acid Brick</td>
<td>9.0</td>
</tr>
<tr>
<td>¾ in. (6.4 mm) Rubber Lining</td>
<td>1.2</td>
</tr>
<tr>
<td>3/16 in. (4.8 mm) Stainless Steel Shell</td>
<td>320.0</td>
</tr>
<tr>
<td>Radiation Factor</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Temperature Range

1100 F (593 C) Operating
100 F (38 C) Summer Ambient
1100 F (593 C) - 100 F (38 C) =

\[
R = \frac{9.0}{1.03} + \frac{0.250}{1.2} + \frac{0.188}{320.0} + 0.33
\]

\[
R = 0.50 + 0.20 + \text{trace} + 0.33
\]

\[
R = 1.03
\]

\[
\Delta T_1 = 0.50 \times 970.8 = 485.4 \text{ F (251.8 C)}
\]

\[
1100 \text{ F (593 C)} - 485.4 \text{ F (251.8 C)} = 614.6 \text{ F (323.6 C)}
\]

\[
\Delta T_2 = 0.20 \times 970.8 = 194.2 \text{ F (90.1 C)}
\]

\[
614.6 \text{ F (323.6 C)} - 194.2 \text{ F (90.1 C)} = 420.4 \text{ F (215.7 C)}
\]

Our problem with the proposed lining as indicated in the initial thermal calculation is that the temperature on the rubber membrane is in excess of its 180 F (82 C) limit. On analyzing the operating conditions of the Venturi Scrubber we realize that the actual operating temperature in the quench zone will be between 400 F (204 C) and 600 F (316 C). We therefore make our next calculation based on a design temperature of 600 F (316 C). To reduce the temperature to a safe limit for the rubber membrane, it would require a brick lining in excess of 27 in. (686 mm) as shown in Fig. 3.
into the lining two new materials to reduce the inlet area must be silicate type to meet temperature requirements, but the furan or phenolic mortar must be used in the scrubbing area because of the water solubility of the silicate mortars. We paper. The alumina silicate paper functions as a thermal shock expected in the quenching section.

In our next thermal calculation we introduce two new materials to reduce the thickness of the acid brick. These two materials are the borosilicate block and the alumina silicate fiber paper. The alumina silicate paper functions as a bond breaker between the acid brick and the borosilicate block. This is necessary to reduce the abrasion of the borosilicate block by the acid brick during cycles of expansion and contraction. It also is beneficial to the thermal gradient. The calculation of this new thermal is shown in Fig. 4.

The Type H Fireclay acid brick proposed is a correct selection for the temperatures involved and thermal shock expected in the quenching section.

The mortar selection of the high temperature inlet area must be a silicate type to meet temperature requirements, but the furan or phenolic mortar must be used in the scrubbing area because of the water solubility of the silicate mortars. We determine the scrubbing medium impingement area

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**FIG. 3 BRICK THERMAL (See Chart 1)**

<table>
<thead>
<tr>
<th>Lining</th>
<th>K-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 in. (686 mm) Acid Brick</td>
<td>9.0</td>
</tr>
<tr>
<td>⅛ in. (6.4 mm) Rubber Lining</td>
<td>1.2</td>
</tr>
<tr>
<td>3/16 in. (4.8 mm) Stainless Steel Shell</td>
<td>320.0</td>
</tr>
<tr>
<td>Radiation Factor</td>
<td>0.33</td>
</tr>
</tbody>
</table>

**FIG. 4 NEW THERMAL (See Chart 1)**

<table>
<thead>
<tr>
<th>Lining</th>
<th>K-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>4⅛ in. (114 mm) Acid Brick</td>
<td>9.0</td>
</tr>
<tr>
<td>⅛ in. (12.7 mm) Alumina Silicate Paper</td>
<td>0.5</td>
</tr>
<tr>
<td>2 in. (51 mm) Pennguard</td>
<td>0.75</td>
</tr>
<tr>
<td>1/8 in. (3.2 mm) Alumina Silicate Paper (wetted with mortar)</td>
<td>1.37</td>
</tr>
<tr>
<td>⅛ in. (6.4 mm) Rubber Lining</td>
<td>0.20</td>
</tr>
<tr>
<td>3/16 in. (4.8 mm) Stainless Steel Shell</td>
<td>320.0</td>
</tr>
<tr>
<td>Radiation Factor</td>
<td>0.33</td>
</tr>
</tbody>
</table>

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The Type H Fireclay acid brick proposed is a correct selection for the temperatures involved and thermal shock expected in the quenching section.

The mortar selection of the high temperature inlet area must be a silicate type to meet temperature requirements, but the furan or phenolic mortar must be used in the scrubbing area because of the water solubility of the silicate mortars. We determine the scrubbing medium impingement area

where the mortar change will take place. Reviewing our previous information in material selection, this particular unit’s major condition is high inlet temperature. The detailed drawing shown in Chart 1 indicates the lining selected based on the above design information which was installed in the unit.
in August 1976. The unit was placed in service in early September 1976. In November of that year we inspected the lining when the unit was down for repairs to the sludge burner. The scrubber lining in the medium impingement area and approximately one brick course or 9 in. (229 mm) above showed deterioration in the silicate mortar joints. We have determined then from this unit and upon inspection of two other units with similar operating conditions that spray nozzle wear and overspray of the quench medium requires that the low temperature furan mortar be used for laying the brick at least one course above the scrubbing medium impingement area. The unit was again placed in service immediately after the deteriorated joints were repointed with furan mortar. It was then operated until the next scheduled plant shutdown in April 1978. At this time we inspected the lining and found the following:

**INSPECTION RESULTS**

1. Spalling of brick in venturi quench area.
2. Cracks in fused quartz venturi nozzle and quartz spray nozzle liners.
3. Heavy joint deterioration in venturi quench area.
4. Through the deteriorated joints we probed with a welding rod observing visually that the alumina silicate fiber paper and the borosilicate glass block were in good condition.
5. Visual inspection of the shell exterior showed no corrosion or hot spots indicating the integrity of the total lining system.

As the visual inspection showed excessive deterioration of the brick portion of the lining, we checked operating procedures and found that the sand filled bottom in this type unit requires, during idle week-end periods, a minimum temperature of 500 F (260 C) be maintained for easy start-up. This stand-by temperature was maintained even though the quenching medium was shut down. On Monday morning the scrubbing medium was returned to the scrubber while the unit was in this hot condition.

What we observed in our inspection was excessive spalling conditions due to a temperature rise in the Venturi section of 500 F (260 C) for a two day period and then a rapid cooling of the area when the scrubbing medium was returned to the unit. Also, the 500 F (260 C) temperature exceeded the service temperature of the furan mortars causing mortar joint deterioration. The broken venturi nozzle liner was removed to eliminate a build-up of slag in the Venturi area that had occurred and all brickwork was repointed.

**CONCLUSION**

Our observations indicate that it is practical and possible to design ceramic linings for high temperature scrubbers with reasonable reliability. The use of a rigid borosilicate foam glass insulation provides tight linings of reduced thickness with reasonable safeguards to protect membrane and vessel substrate.

**ACKNOWLEDGMENTS**


**REFERENCES**


**Key Words**

Concentration
Scrubber
System
Thermal