Selection of Refractory Bricks for Use in Lime Sludge Kilns

Corrosion in Pulp and Paper Mills and Biorefineries
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Outline

• Function of the refractory lining
• Selection of refractory bricks
• Recommended refractory linings
Key Factors to Optimize Performance of the Refractory Lining

- Operating Conditions
- Material Selection
- Burner Design

Optimized Refractory Lining
Function of the Refractory Lining

• A kiln cannot be operated without the use of a refractory lining to insulate the metal shell. This is because the temperatures required for calcination are so high that a bare metal shell would be destroyed.

• The most important physical characteristics of the refractory lining are its ability to withstand high temperatures and direct chemical attack by the sodium compounds that are introduced into the kiln with the mud.

• The secondary role of the refractory lining is to reduce heat losses through the shell so that the kiln can be operated with the highest energy efficiency possible.
Modern kilns typically use a dual lining consisting of a high temperature brick at the inner hot surface backed by an insulating brick next to the steel shell. The intent of the dual lining is to minimize shell heat losses.
Factors to Consider in Selecting Refractory Materials

- Resistance to chemical attack (solids and gases)
- Abrasion resistance
- Thermal conductivity
- Resistance to spalling
- Fusion and softening temperatures
- Strength
- Cost
Refractory Zones in the Lime Kiln

- **Burning Zone** (~10 diameters)
- **Castable**
- **High Duty Fireclay** (40-50% Al₂O₃)
- **High Alumina** (60-70% Al₂O₃)
Discharge Dam

- Dams are installed at the discharge of the kiln to increase the depth and heat transfer to the bed, increase the residence time of the solids, and help to protect the refractory lining from being overheated in the hottest region of the kiln.

- The heights of dams vary between 15 to 25 percent of the inner diameter of the kiln. More recently, the trend has been to install shorter dams.

\[ h_d = kD_k \text{ where } k = 0.15 \text{ to } 0.25 \]
Cup Testing High Alumina Refractory Bricks

Cut test bricks into 5 cm blocks

Drill 25.4 mm diameter hole to a depth of 25.4 mm
Cup Testing High Alumina Refractory Bricks

Fill with 50 grams of dried mud

Heat samples to 1500°C and hold for 4 hours, cool for 12 hours

Section for examination
Cup Testing High Alumina Refractory Bricks

Cross-sectional area used to measure the extent of chemical reaction.
## Typical Composition of Lime Mud

<table>
<thead>
<tr>
<th>Mill Location</th>
<th>Al (ppm)</th>
<th>Fe (ppm)</th>
<th>Mg (ppm)</th>
<th>Mn (ppm)</th>
<th>Na (ppm)</th>
<th>P (ppm)</th>
<th>Si (ppm)</th>
<th>Total S (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill #1</td>
<td>807</td>
<td>506</td>
<td>2870</td>
<td>43</td>
<td>7800</td>
<td>5000</td>
<td>910</td>
<td>0.09</td>
</tr>
<tr>
<td>Mill #2</td>
<td>726</td>
<td>753</td>
<td>3710</td>
<td>117</td>
<td>8500</td>
<td>3000</td>
<td>860</td>
<td>0.18</td>
</tr>
<tr>
<td>Mill #3</td>
<td>92</td>
<td>120</td>
<td>1760</td>
<td>158</td>
<td>7200</td>
<td>1070</td>
<td>&lt;200†</td>
<td>0.06</td>
</tr>
<tr>
<td>Mill #4</td>
<td>742</td>
<td>691</td>
<td>2350</td>
<td>81</td>
<td>5800</td>
<td>827</td>
<td>1300</td>
<td>0.12</td>
</tr>
<tr>
<td>Mill #5</td>
<td>1010</td>
<td>795</td>
<td>5470</td>
<td>98</td>
<td>6200</td>
<td>2230</td>
<td>990</td>
<td>0.17</td>
</tr>
<tr>
<td>Mill #6</td>
<td>763</td>
<td>1310</td>
<td>2700</td>
<td>260</td>
<td>11000</td>
<td>2460</td>
<td>1000</td>
<td>0.31</td>
</tr>
<tr>
<td>Mill #7</td>
<td>1900</td>
<td>2150</td>
<td>6600</td>
<td>210</td>
<td>7900</td>
<td>6790</td>
<td>1100</td>
<td>0.33</td>
</tr>
<tr>
<td>Mill #8</td>
<td>376</td>
<td>1040</td>
<td>5410</td>
<td>305</td>
<td>7800</td>
<td>7440</td>
<td>1100</td>
<td>0.18</td>
</tr>
<tr>
<td>Average</td>
<td>802</td>
<td>921</td>
<td>3859</td>
<td>159</td>
<td>7775</td>
<td>3602</td>
<td>1037</td>
<td>0.18</td>
</tr>
</tbody>
</table>

†Below limit of detection
Cross-Sections Showing Impact of Mud Compositions on Penetration
Impact of Mud Composition on Penetration

- No relationship between penetration depth of reaction and mud composition and the area of penetration.

- Mud from Mill #1 was used for the cup tests reported here.
Cross-Sections for 70% High Alumina Bricks

70% High Alumina Bricks

Brick #1

Brick #2

Brick #3

Brick #4

Brick #5

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Cross-Sections for 60% High Alumina Bricks

Brick #6
Brick #7
Brick #8
Brick #9
Brick #10

Brick #11
Brick #12
Brick #13
Brick #14

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Penetration for 60% and 70% High Alumina Bricks

- **70% Alumina Brick**
  - Avg. 8.71 cm²

- **60% Alumina Brick**
  - Avg. 5.61 cm²

Sample Numbers:
- Brick #1
- Brick #2
- Brick #3
- Brick #4
- Brick #5
- Brick #6
- Brick #7
- Brick #8
- Brick #9
- Brick #10
- Brick #11
- Brick #12
- Brick #13
- Brick #14

Selection of Refractory Bricks
Photomicrograph Showing Unreacted Matrix for High Alumina Bricks

70% High Alumina Brick  
Brick #1

60% High Alumina Brick  
Brick #12

- Brick #1 (70% alumina) is made using bauxite and corundum (to meet alumina content).
- Brick #12 (60% alumina) is made using Andalusite (naturally occurring mineral that transforms to mullite when heated above 1000°C during manufacturing).
## Impact of Corundum Content on Penetration

<table>
<thead>
<tr>
<th>Brick Number</th>
<th>Classification</th>
<th>Penetration (cm²)</th>
<th>Corundum Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70% Alumina</td>
<td>7.55</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>8.38</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>10.38</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>9.03</td>
<td>21</td>
</tr>
<tr>
<td>5</td>
<td>70% Alumina</td>
<td>8.19</td>
<td>18</td>
</tr>
<tr>
<td>6</td>
<td>60% Alumina</td>
<td>7.61</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>7.61</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>5.68</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>5.74</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>5.29</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>4.58</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>4.19</td>
<td>Trace</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>5.16</td>
<td>Trace</td>
</tr>
<tr>
<td>14</td>
<td>60% Alumina</td>
<td>4.84</td>
<td>Trace</td>
</tr>
</tbody>
</table>

Corundum is used as starting material in the manufacture of these bricks.
Cross-Sections for 70% High Alumina Plastics

70% High Alumina Plastics

Plastic #1

Plastic #2

Plastic #3

In terms of chemical reaction with mud, plastics offer no advantage over bricks.
Impact of Temperature on Reaction of Mud with High Alumina Bricks

<table>
<thead>
<tr>
<th>Material</th>
<th>Test Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1400°C</td>
</tr>
<tr>
<td>70% High Alumina Brick</td>
<td>![Image]</td>
</tr>
<tr>
<td>60% High Alumina Brick (&lt;10% corundum)</td>
<td>![Image]</td>
</tr>
</tbody>
</table>

For high alumina bricks, the mud reacts with the brick to form liquid calcium alumino-silicates above 1450°C. Once formed, these liquids can readily penetrate deep into the matrix of the brick leading to rapid erosion and failure of the lining.
Chemical Reactions of Soda with Alumina and Silica

\[ \text{Na}_2\text{O} + 2\ \text{SiO}_2 + \leq 0.2\ \text{Al}_2\text{O}_3 \rightarrow \text{Natrosilite (Na}_2\text{Si}_2\text{O}_5) + \text{Liquid} \]

\[ \text{Na}_2\text{O} + 2\ \text{SiO}_2 + \geq 0.2\ \text{Al}_2\text{O}_3 \rightarrow \text{Nepheline (Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2) + \text{Liquid} \]

\[ \text{Na}_2\text{O} + \geq 0.4\ \text{Al}_2\text{O}_3 + \geq 3.5\ \text{SiO}_2 \rightarrow \text{Albite (Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2) + \text{Liquid} \]

\[ \text{Na}_2\text{O} + \leq 0.5\ \text{Al}_2\text{O}_3 + \leq 1.5\ \text{SiO}_2 \rightarrow \text{Na}_2\text{SiO}_3 + \text{Liquid} \]

\[ \text{Na}_2\text{O} + \geq 0.5\ \text{Al}_2\text{O}_3 + \geq 1.5\ \text{SiO}_2 \rightarrow \text{Nephelite (Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2) + \text{Liquid} \]

The hot-face temperatures of the bricks are thought to approach 1500°C which enables the formation of new sodium silicate phases accompanied by liquid.
In some kilns a coating of material buildups on the inner refractory wall. These coatings are typically between 2 and 10 cm thick.
Temperatures Profiles for the Refractory Lining

Above 1450°C the mud reacts with the alumina and silica in the brick to form liquids (rapid erosion)

Maximum working Temperature Diatomite based insulating bricks are 950°C

The presence of a coating helps in keeping both the hot face and insulating bricks below their maximum working temperatures.
Increasing the firing rate increases peak temperatures of the refractory lining. The increase in temperature is more pronounced once all carbonate has been completely calcined.
Localized Overheating of the Refractory Lining

Examples of concave heating pit formation (commonly referred to as "duck nesting") in refractory linings caused by flame impingement on the lining.
Magnesia bricks do not react with mud to form liquids at the operating temperatures in lime sludge kilns.
The shell temperatures of the kiln lined with the basic brick are nearly double those for the kiln lined with insulated high alumina brick.
Comparison of Shell Heat Loss for Refractory Linings Made Using Basic and High Alumina Bricks

Since the heat transfer due to radiation is proportional to the fourth power of temperature, the corresponding shell heat losses for kilns lined with uninsulated basic brick can be as much as four times higher than those lined with insulated high alumina brick.
Infiltration of Basic Refractory Bricks by Volatile Components

Basic refractories do not react with lime mud to form liquids at the operating temperatures in lime sludge kilns. Physical infiltration of sodium and potassium salts and condensation is possible. The salt condensation leads to densified horizons in the basic bricks which become brittle. If the lining is exposed to thermo or mechanical loads, the salt infiltrated horizons can spall off.
Examples of Refractory Bricks Used in Lime Kilns

<table>
<thead>
<tr>
<th>Classification</th>
<th>Zone</th>
<th>Density (gm/cm³)</th>
<th>Thermal Conductivity (W/m°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hot Face Lining</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic</td>
<td>Burning</td>
<td>2.8</td>
<td>3.1</td>
</tr>
<tr>
<td>70% Al₂O₃</td>
<td>Burning</td>
<td>2.7</td>
<td>1.7</td>
</tr>
<tr>
<td>60% Al₂O₃</td>
<td>Burning</td>
<td>2.6</td>
<td>1.6</td>
</tr>
<tr>
<td>40% Al₂O₃</td>
<td>Preheating</td>
<td>2.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Super Duty</td>
<td>Preheating</td>
<td>2.2</td>
<td>1.1</td>
</tr>
<tr>
<td>30% Al₂O₃</td>
<td>Preheating</td>
<td>2.1</td>
<td>1.1</td>
</tr>
<tr>
<td>High Duty</td>
<td>Preheating</td>
<td>2.1</td>
<td>1.1</td>
</tr>
<tr>
<td>&lt;30% Al₂O₃</td>
<td>Preheating</td>
<td>1.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Low Al₂O₃ Fireclay</td>
<td>Drying</td>
<td>2.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Low Cement Castable</td>
<td>Drying</td>
<td>2.3</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Backup Lining</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;30% Al₂O₃</td>
<td>Burning</td>
<td>1.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Low Al₂O₃ Fireclay</td>
<td>Preheating</td>
<td>0.9</td>
<td>0.2</td>
</tr>
<tr>
<td>Diatomite</td>
<td>Preheating</td>
<td>0.9</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Selecting Refractory Bricks
Commonly Used Refractory Linings in Lime Sludge Kilns

Conventional Dual Brick Lining

Dual Brick Lining with Single Layer of Low Alumina Fireclay in Preheating Zone
Brick Thickness Measurements for 60% High Alumina Bricks

- The burning zone refractory lining should go 2 to 3 years between major repairs.
- Paying more for bricks does not always improve performance (Brick #12 is three time more expensive than Brick #8).
Refractory Lining for Heavily Loaded Lime Sludge Kilns

Dual Lining Using Magnesia and High Alumina Bricks in the Burning Zone

Outlet	Dam	Magesite Brick	60% Alumina Brick	Super Duty	High Duty	Castable	Bare Shell

High Duty	Insulating Brick
Shell Temperature Monitors Should be Used When Making Changes to the Refractory Lining

Thermal Imaging System

Benefits of Monitoring Shell Temperatures

- Detect hotspots on the kiln shell due to refractory lining loss, damage or wear
- Detect ring formation
- Extend service life of kiln shell and refractory lining
Temperature Increase Due to Magnesia Brick upto 150°C

Access Door

1st Tire

Magnesia Brick

2nd Tire

Selection of Refractory Bricks
Conclusions

- Kilns could not be run without refractory linings because the temperatures required to calcine the mud are so high they would destroy the metal shell.
- Most kilns use a dual brick lining to reduce shell heat losses in burning and preheat zones.
- Insulating the refractory lining can reduce heat consumption by 1.5 GJ/t CaO.
- High Alumina (60% or 70% Al$_2$O$_3$) refractory bricks are the most commonly used materials in hot face of the burning zone.
- The use of single component low alumina fireclay refractory bricks in the preheat zone is gaining more acceptance within the industry.
- Magnesia bricks can be use as a means to extend the working life of the refractory lining in the burning zone for heavily loaded kilns.
Final Comments

- Optimizing the performance of the refractory lining is an ongoing process.
- Care must be taken to keep good records
  - Installation (type of refractory and location).
  - Inspection (wear patterns and thickness measurements).
- Careful planning of schedule maintenance (avoid patchwork of odds and ends).
- Work with the brick suppliers and contractors to ensure the refractory lining is properly installed.