Lime Kiln Principles And Operations

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Outline

• Lime kiln equipment
  – flames, chains, refractories
  – product coolers, external mud dryers
• Lime kiln energy efficiency
• Alternative fuels for lime kilns
Exterior Of A Lime Reburning Kiln

- Burner
- Reburn lime discharge
- Flue gas to the ID fan
- Lime mud slurry

Interior Of A Lime Reburning Kiln

- Flame
- Lifters
- Chains
- Dam
- Refractory
Rotary Kiln Flame Shapes

- Long lazy flame
- Short bushy flame
- Compact medium-length flame

Rotary Kiln Chain Systems

- Low-density curtain chain
- High-density curtain chain
- Garland chain
Lime Kiln Chain Systems

Rotary Kiln Refractory Systems

- Single-Brick System
  - Refractory bricks

- Two-Brick System
  - Insulating bricks
  - Refractory bricks
  - Steel Shell
Refractory Wastage

- Most refractory damage due to wastage
  - Smooth, “bird bath” refractory thinning
- Due to high temperature chemical attack
- Protect refractory with a coating of lime
- Operate kiln for lower refractory face temp
  - Low primary air flow, avoid flame impingement
  - Cold-end excess $O_2 > 1\frac{1}{2}\%$

Refractory Damage Photos

- Refractory Wastage
- Refractory Collapse
**Lifters And Discharge Dams**

- Lifters
  - Cold end of kiln
  - Lifters
- Discharge Dam
  - Dam
  - Hot end of kiln
  - Lime bed

**Rotary Kiln Product Coolers**

- Satellite Product Coolers
- Induced secondary air
- Reburned lime
External Lime Mud Drying

- Mud screw
- Kiln
- Electrostatic precipitator
- Precipitator catch
- Cyclone
- Gas

Fans, Draft, And $O_2$

- PA fan only for flame shaping
- ID fan is main air moving fan
  - Use ID fan to control $O_2$
  - Often limits production capacity
  - Wet scrubber is main flow restriction
Lime Kiln Heat Rate

- Heat rate is a measure of energy efficiency
  - Units are MM Btu/ton CaO or GJ/tonne CaO
  - Often stated as MM Btu/ton “product”
- Typical range
  - 5 to 9 MM Btu/ton CaO
  - 5.8 to 10.5 GJ/tonne CaO
  - Lower is better

Lime Kiln Energy Balance Components

- Drying
- Calcining: \[ \text{CaCO}_3 + \text{heat} \rightarrow \text{CaO} + \text{CO}_2 \]
- Losses
  - Heat loss through shell
  - Heat loss in hot lime product
  - Heat loss with gas and dust exiting at cold end
- A portion of fuel higher heating value is unavailable
  - HHV is measured and reported
  - Only Lower Heating Value (LHV) is actually available
### Example for Kiln Heat Rate

#### KILN PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Nat Gas</td>
</tr>
<tr>
<td>Production rate</td>
<td>250 TPD</td>
</tr>
<tr>
<td>Mud dry solids</td>
<td>78%</td>
</tr>
<tr>
<td>Kiln exit O2</td>
<td>3%</td>
</tr>
<tr>
<td>Lime availability</td>
<td>85%</td>
</tr>
<tr>
<td>Dust loss</td>
<td>18%</td>
</tr>
<tr>
<td>Product temp</td>
<td>600°F</td>
</tr>
<tr>
<td>Cold end gas temp</td>
<td>600°F</td>
</tr>
<tr>
<td>Shell Heat Loss</td>
<td>11.4 MM Btu/hr</td>
</tr>
</tbody>
</table>

### Lime Kiln Heat Rate

- **Overall Heat Rate** = 8.4 MM Btu/ton CaO

<table>
<thead>
<tr>
<th>Contribution</th>
<th>Heat rate</th>
<th>Fraction</th>
<th>Remedy</th>
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</thead>
<tbody>
<tr>
<td>Calcining reaction</td>
<td>2.82</td>
<td>34%</td>
<td>No change possible</td>
</tr>
<tr>
<td>Heat to evap water</td>
<td>1.75</td>
<td>21%</td>
<td>Increase mud dry solids</td>
</tr>
<tr>
<td>Heat in exit gas</td>
<td>1.50</td>
<td>18%</td>
<td>Decrease exit gas temp</td>
</tr>
<tr>
<td>Shell heat loss</td>
<td>1.10</td>
<td>13%</td>
<td>Insulating refractory</td>
</tr>
<tr>
<td>LHV/HHV loss</td>
<td>0.82</td>
<td>10%</td>
<td>Change fuel</td>
</tr>
<tr>
<td>Heat in product</td>
<td>0.29</td>
<td>3%</td>
<td>Product coolers</td>
</tr>
<tr>
<td>Heat in dust</td>
<td>0.11</td>
<td>1%</td>
<td>Improve chain system</td>
</tr>
</tbody>
</table>
Caution With Heat Rate Calculation

- Gives instantaneous value
  - Doesn't include down time, upsets
- Good to assess where improvements needed
- Some changes affect more than one parameter
  - Refractory changes shell loss & exit temp
  - Mud solids affects evaporation loss and exit temp
  - Fuel changes LHV/HHV, exit gas temp, and dust loss

Impact of Mud Dry Solids on Heat Rate

![Graph showing the impact of lime mud dry solids on heat rate with data points and a trend line labeled Mill data.](image)
### Major Heat Rate Improvements

<table>
<thead>
<tr>
<th>KILN PARAMETERS</th>
<th>Base</th>
<th>Refractory</th>
<th>Fuel Type</th>
<th>Chains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Nat Gas</td>
<td>Nat Gas</td>
<td>Fuel Oil</td>
<td>Nat Gas</td>
</tr>
<tr>
<td>Production rate, TPD</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Mud dry solids</td>
<td>78%</td>
<td>78%</td>
<td>78%</td>
<td>78%</td>
</tr>
<tr>
<td>Kiln exit O2</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Lime availability</td>
<td>85%</td>
<td>85%</td>
<td>85%</td>
<td>85%</td>
</tr>
<tr>
<td>Dust loss</td>
<td>18%</td>
<td>12%</td>
<td>18%</td>
<td>18%</td>
</tr>
<tr>
<td>Product temp, ºF</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Cold end gas temp, ºF</td>
<td>600</td>
<td>475</td>
<td>500</td>
<td>525</td>
</tr>
<tr>
<td>Shell Heat Loss, MM Btu/hr</td>
<td>11.4</td>
<td>6.3</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Heat Rate, MM Btu/ton</td>
<td>8.4</td>
<td>7.0</td>
<td>7.4</td>
<td>8.0</td>
</tr>
<tr>
<td>Change</td>
<td>-17%</td>
<td>-11%</td>
<td>-4%</td>
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</tr>
</tbody>
</table>

### Minor Heat Rate Improvements

<table>
<thead>
<tr>
<th>KILN PARAMETERS</th>
<th>Base</th>
<th>Excess air</th>
<th>Dust</th>
<th>Inerts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Nat Gas</td>
<td>Nat Gas</td>
<td>Nat Gas</td>
<td>Nat Gas</td>
</tr>
<tr>
<td>Production rate, TPD</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Mud dry solids</td>
<td>78%</td>
<td>78%</td>
<td>78%</td>
<td>78%</td>
</tr>
<tr>
<td>Kiln exit O2</td>
<td>3%</td>
<td>2%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Lime availability</td>
<td>85%</td>
<td>85%</td>
<td>85%</td>
<td>92%</td>
</tr>
<tr>
<td>Dust loss</td>
<td>18%</td>
<td>18%</td>
<td>12%</td>
<td>18%</td>
</tr>
<tr>
<td>Product temp, ºF</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Cold end gas temp, ºF</td>
<td>600</td>
<td>575</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Shell Heat Loss, MM Btu/hr</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Heat Rate, MM Btu/ton</td>
<td>8.4</td>
<td>8.1</td>
<td>8.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Change</td>
<td>-3%</td>
<td>-3%</td>
<td>-2%</td>
<td></td>
</tr>
</tbody>
</table>
Common Lime Reburning Kiln Fuels

• Nat gas and fuel oil are most common
  – Fuel oil is more efficient, gives higher capacity
• Petroleum coke
  – Many applications, low cost
  – Sulfur and metals can be high
  – Thermal NOx can be high
  – Improves heat rate

Other Solid/Liquid Kiln Fuels

• Wood and bark powder
  – NPEs can be high
  – Lime purge & makeup needed to control NPEs
• Lignin
  – Sulfur can be high
• Pyrolysis oils
  – Not currently used, pH & μ possible issues
Gasification Fuels

- Coal, wood and other fuels can be gasified
- Fuel-gas can be used to fire kiln
  - Similar to natural gas
  - Lower inert level, well established technology
  - On-line availability ~ 85%
  - Wet gasifier feedstocks derate kiln
  - Burner and chains must be designed for fuel-gas

Fuels From the Pulp Mill

- Turpentine or methanol liquid
- Stripper Off-Gas (SOG)
- Non-condensable gas (NCG)
  - Can be wet and sulfur level can be high
- Tall oil and tall oil pitch
  - Can fire 100% tall oil, similar to fuel oil
  - 16,000 Btu/lb and low sulfur
How To Improve Lime Kiln Performance

- Improve refractory system
  - thicker bricks, two-brick system
- Switch fuels
- Improve chain system
  - amount for heat transfer, layout for dust
- Improve ID fan/scrubber
- Dry mud externally