Lime Sludge Kiln Operation

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Schematic Diagram of Pulp & Paper Mill

Function of Lime Kiln

- The causticizing process that produces white liquor from green liquor consumes lime (CaO) and produces lime mud (CaCO₃) as a by-product.
- The function of the lime kiln is to convert CaCO₃ back to CaO for reuse in the causticizing process.

$$CaCO_3 \leftrightarrow CaO + CO_2$$
Everett Lime Kiln
Refractory Layout

150-200mm High Alumina Brick

40-60mm Insulating Brick
The zones in the kiln are easy to distinguish using the bulk solids temperature profile. The drying zone is the region where the bulk solids temperature is constant, at a value of about 175°F. The bulk solids temperature in the calcining zone is constant at 1600°F, though the surface temperature of the solids can be as much as 500°F higher. The peak flame temperature is near 2800°F, with an exit gas temperature around 400°F.
In order to produce a usable product, the kiln must not only dry and calcine the mud, but also agglomerate the dry mud (powder) into nodules so it can be handled by the system. Typically, the lime nodules vary in size from 0.5 to 2 inches in diameter. Sodium compounds play a key role in forming the nodules.
Structure of Lime Nodule

Polished Thin Section of Lime Nodule
(approximately 15 microns thick)

- Lime Particles
- Epoxy Resin
- Dark Matrix Phase Coating Lime Particles (rich in Fe, Al, Si, Na)
Theoretical Growth Rate Curve for Lime Nodules

![Theoretical Growth Rate Curve for Lime Nodules](image)

- **Rate of Change of Average Nodule Diameter x10^2 (in/slump)**
- **Number of Bed Slumps**

Key Phases:
- Nucleation
- Coalescence
- Nodule Growth
Nuclei Formation

In lime sludge kilns, just below the calcination temperature (~1500 to 1600°F) the soda compounds in the mud melt to form a layer of liquid on the surface of the individual particles. Only a thin coating of liquid on the surface of the particles will cause them behave like a bulk liquid. In the presence of these liquids, to reduce surface free energy, the mud particles virtually explode into small nuclei after a few revolutions of the kiln.
Nuclei Coalescence

On further tumbling of the charge, the nuclei collide with one another, with some of the collisions forming capillary necks leading to successful coalescence. During this stage the growth rate of the nodules reaches a maximum. Eventually, as the diameter of the nodules increase, the efficiency of coalescence decreases as separating torque on the coalescence twins increases and less liquid becomes available on the surface of the nodules.
Nodule Growth

The growth rate growth rate continues to decline because of the low efficiency of coalescence and other mechanisms like layering and abrasion transfer are inherently slower.
Location of Kiln Rings

1. **Dust Rings**: Dust rings occasionally form during startups. Dust is picked up by the secondary air as it moves through firing hood or coolers and deposited on the nose ring or discharge dam. The exact mechanism of formation is not completely understood. These rings are not strong enough to support their weight and normally fallout shortly after startup. They do not pose a threat to production.

2. **Mid-Kiln Rings (commonly referred to as “100 foot rings”)**: Sodium compounds form liquids as the mud approaches the calcination temperature (~1500 to 1600°F). The formation of these liquids on the surface of the mud particles in combination with the rolling action of the bed causes them to agglomerate into nodules. At the same, rather than sticking to each other, some of the particles may stick to the wall forming a ring. Initially, the ring is soft and contains both CaCO₃ and CaO. Later, as the ring thickens or as operating conditions change, the ring cools and the CaO reacts with CO₂ to reform CaCO₃. As recarbonation occurs, the ring strengthens and will no longer fall out under its own weight. All lime sludge kilns have this ring. The size of the ring is dependent on the sodium content of the mud and the variability of the kiln operation.

3. **Mud Rings**: The moisture level of the mud leaving the chain section should be less than 5%. Excessively wet mud, greater than 15%, downhill from the chain section can stick to the wall forming rings. Typically, these rings form in the first few hours following a sheet drop and manual washing of the drum filter. The rings are very soft and eventually, they dry and fall out. Pieces of the ring will show up at the front end of the kiln as balls and/or slabs. The installation of new more efficient mud filters and continuous cleaning systems have greatly reduced the occurrence of these rings.
Location of Kiln Rings (continued)

4. **Burning Zone Rings**: Rings are sometimes found near the end of the flame. The appearance of these is more common in lime kilns fired with oil or petroleum coke. The exact mechanism causing these rings is not well understood. The ash content of the fuel may play a key role. While no single chemical species can be pinpointed, fuels with low ash contents or fuels with very high ash melting temperatures are preferred. The flame shape (aerodynamics) and dust levels in the front of the kiln play key roles in forming these rings.

5. **Soda Balls**: The dust level in the freeboard above the bed is high. Up to 25% of the dry solids entering the kiln is lost as dust with the exist gases. The temperatures of the dust particles in the freeboard equilibrate with the gas temperatures. As is the case for particles in the bed, the sodium compounds form liquids when the dust particles traveling in the gas reach 1500°F. If the gas temperature distributions along the kiln are such that the sodium in the dust particles form liquids as they pass through the chain section, they may stick to the surface of the chain. Overtime, the deposits grow and due to the rolling action of the bed form ball like structures that hang on the chains. The extra weight from these deposits eventually overload the chains causing them to break. Improved chain system designs have greatly reduced the occurrence of these deposits.
Mechanism for Mid-Kiln Ring Formation

- The same mechanisms that form nodules cause mid-kiln rings to form on the refractory lining.
- The nuclei may stick to one another or the refractory lining forming a ring.
Strength of Mid-Kiln Ring

The strength of mid-kiln rings increases with:

- **Size** - Thicker longer rings are much stronger and harder to remove

- **Recarbonization** ($CaO + CO_2 \rightarrow CaCO_3$) - Reforming $CaCO_3$ from $CaO$ in the ring strengthens it to the point it will not fall out
# Mud Compositions (early 1990’s)

<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>S(total) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill #1</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 #2</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 #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>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 #5</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>Mill #6</td>
<td>1560</td>
<td>1450</td>
<td>5430</td>
<td>81</td>
<td>7860</td>
<td>8340</td>
<td>741</td>
<td>0.15</td>
</tr>
<tr>
<td>Mill #7</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 #8</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>
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<tr>
<td><strong>Average</strong></td>
<td>760</td>
<td>833</td>
<td>3713</td>
<td>143</td>
<td>7770</td>
<td>3796</td>
<td>986</td>
<td>0.16</td>
</tr>
</tbody>
</table>

† Below limit of detection

isplaychart

- **Occasional Problems with Rings**
- **Moderate Problems with Rings**
- **Severe Problems with Rings**
Factors Impacting High Temperature Agglomeration

- Chemical composition and amount of matrix phase
- Particle size distribution of mud
- Lime purge rates
- Sources of fresh lime
- Impurities in wood chips
- Handling of dust recycle
- Ash composition of fuel
- Composition of refractory lining
- Chemicals used for make up
Impact of Production on Ring Formation
125 tpd

Production: 500 tpd
Firing Rate: 2400 ft³/min
Mud Solids: 50%
XS Air: 10%
Carbonate: 2.5%
Availability: 90.7%
Exit Temp: 175°F

Solids Temperature

Distance Along Kiln Axis (ft)

Gas Flow
Solids Flow
<table>
<thead>
<tr>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 tpd</td>
<td>635 ft³/min</td>
<td>75%</td>
<td>10%</td>
<td>2.5%</td>
<td>90.7%</td>
<td>207°F</td>
</tr>
</tbody>
</table>

**Solids Temperature**

```
Distance Along Kiln Axis (ft)
```

```
- Gas Flow
- Solids Flow
```
200 tpd

<table>
<thead>
<tr>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>2400</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td>50</td>
<td>400</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>200 tpd</td>
<td>845 ft³/min</td>
<td>75%</td>
<td>10%</td>
<td>2.5%</td>
<td>90.7%</td>
<td>305°F</td>
</tr>
</tbody>
</table>

Solids Temperature

Distance Along Kiln Axis (ft)
250 tpd

Production: 500
Firing Rate: 2400
Mud Solids: 100
XS Air: 50
Carbonate: 25
Availability: 100
Exit Temp: 1000

250tpd
1080ft³/min
75%
10%
2.5%
90.7%
419°F

Solids Temperature

Distance Along Kiln Axis (ft)

Gas Flow
Solids Flow
300 tpd

Production | Firing Rate | Mud Solids | XS Air | Carbonate | Availability | Exit Temp
---|---|---|---|---|---|---
500 | 2400 | 100 | 50 | 25 | 100 | 1000
50 | 400 | 50 | 0 | 0 | 50 | 100
300tpd | 1345ft³/min | 75% | 10% | 2.5% | 90.7% | 538°F

Solids Temperature

Distance Along Kiln Axis (ft)
350 tpd

Production | Firing Rate | Mud Solids | XS Air | Carbonate | Availability | Exit Temp
---|---|---|---|---|---|---
500 | 2400 | 100 | 50 | 25 | 100 | 1000
50 | 400 | 50 | 10 | 0 | 50 | 100

350 tpd | 1642 ft³/min | 75% | 10% | 2.5% | 90.7% | 659°F

Solids Temperature

Distance Along Kiln Axis (ft)

Gas Flow
Solids Flow
## 400 tpd

<table>
<thead>
<tr>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>2400</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td>400tpd</td>
<td>1979 ft³/min</td>
<td>75%</td>
<td>10%</td>
<td>2.5%</td>
<td>90.7%</td>
<td>781°F</td>
</tr>
</tbody>
</table>

![Solids Temperature Graph](image)

**Solids Temperature**

Distance Along Kiln Axis (ft)

![Diagram of Gas and Solids Flow](image)
Impact of Mud Solids on Ring Formation
5% XS Air

Production: 500 - 300tpd
Firing Rate: 2400 - 1295ft³/min
Mud Solids: 100 - 75%
XS Air: 50 - 5%
Carbonate: 25 - 2.5%
Availability: 100 - 90.7%
Exit Temp: 1000 - 478°F

Solids Temperature

Distance Along Kiln Axis (ft)
10% XS Air

<table>
<thead>
<tr>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 tpd</td>
<td>1344 ft³/min</td>
<td>75%</td>
<td>10%</td>
<td>2.5%</td>
<td>90.7%</td>
<td>538°F</td>
</tr>
</tbody>
</table>

Solids Temperature

Distance Along Kiln Axis (ft)
20% XS Air

Production: 300 tpd
Firing Rate: 1459 ft³/min
Mud Solids: 75%
XS Air: 20%
Carbonate: 2.5%
Availability: 90.7%
Exit Temp: 660°F

Solids Temperature

Distance Along Kiln Axis (ft)
30% XS Air

Production: 300tpd
Firing Rate: 1605 ft³/min
Mud Solids: 75%
XS Air: 30%
Carbonate: 2.5%
Availability: 90.7%
Exit Temp: 788°F

Solids Temperature

Distance Along Kiln Axis (ft)
# 40% XS Air

<table>
<thead>
<tr>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>300tpd</td>
<td>1786 ft³/min</td>
<td>75%</td>
<td>40%</td>
<td>2.5%</td>
<td>90.7%</td>
<td>917°F</td>
</tr>
</tbody>
</table>

## Solids Temperature

![Solids Temperature Graph](image)

Distance Along Kiln Axis (ft)
Impact of Mud Solids on Ring Formation
# 60% Mud Solids

<table>
<thead>
<tr>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>300tpd</td>
<td>1580 ft³/min</td>
<td>60%</td>
<td>10%</td>
<td>2.5%</td>
<td>90.7%</td>
<td>381°F</td>
</tr>
</tbody>
</table>

**Solids Temperature**

![Solids Temperature Graph](image)

**Distances along Kiln Axis (ft)**

- Gas Flow
- Solids Flow
## 70% Mud Solids

<table>
<thead>
<tr>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>300tpd</td>
<td>1394 ft³/min</td>
<td>70%</td>
<td>10%</td>
<td>2.5%</td>
<td>90.7%</td>
<td>463°F</td>
</tr>
</tbody>
</table>

### Solids Temperature

![Solids Temperature Chart](chart)

**Distance Along Kiln Axis (ft):**

- 0 ft
- 50 ft
- 100 ft
- 150 ft
- 200 ft
- 250 ft
- 300 ft

**Temperature:**

- 0 to 2000°C

- **Gas Flow:**
  - [Diagram of Gas Flow]

- **Solids Flow:**
  - [Diagram of Solids Flow]
### 75% Mud Solids

<table>
<thead>
<tr>
<th></th>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>300tpd</td>
<td>50</td>
<td>2400</td>
<td>75%</td>
<td>10%</td>
<td>2.5%</td>
<td>90.7%</td>
<td>538°F</td>
</tr>
<tr>
<td>1344 ft³/min</td>
<td>400</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>50</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

**Solids Temperature**

- Distance Along Kiln Axis (ft)
- Distance: 0 to 300 ft
- Temperature: 0 to 2000 °F

**Gas Flow**

**Solids Flow**
80% Mud Solids

Production: 300tpd
Firing Rate: 1344 ft³/min
Mud Solids: 80%
XS Air: 10%
Carbonate: 2.5%
Availability: 90.7%
Exit Temp: 624°F

Solids Temperature

Distance Along Kiln Axis (ft)
90% Mud Solids

Production: 300tpd
Firing Rate: 1259 ft³/min
Mud Solids: 90%
XS Air: 10%
Carbonate: 2.5%
Availability: 90.7%
Exit Temp: 821°F

Solids Temperature

Distance Along Kiln Axis (ft)
Impact of Firing Rate on Ring Formation
**1461 ft³/min**

<table>
<thead>
<tr>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 tpd</td>
<td>1461 ft³/min</td>
<td>75%</td>
<td>10%</td>
<td>0%</td>
<td>90.7%</td>
<td>620°F</td>
</tr>
</tbody>
</table>

**Solids Temperature**

![Solids Temperature Diagram](image)

- **Distance Along Kiln Axis (ft)**
- **Gas Flow**
- **Solids Flow**
1436 ft³/min

Production | Firing Rate | Mud Solids | XS Air | Carbonate | Availability | Exit Temp
---|---|---|---|---|---|---
300tpd | 1436 ft³/min | 75% | 10% | 0% | 90.7% | 599°F

Solids Temperature

Distance Along Kiln Axis (ft)
1419 ft³/min

Production  Firing Rate  Mud Solids  XS Air  Carbonate  Availability  Exit Temp

300 tpd  1419 ft³/min  75%  10%  0%  90.7%  586°F

Solids Temperature

Distance Along Kiln Axis (ft)

Gas Flow
Solids Flow
1344 ft³/min

<table>
<thead>
<tr>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 tpd</td>
<td>1344 ft³/min</td>
<td>75%</td>
<td>10%</td>
<td>2.5%</td>
<td>90.7%</td>
<td>538°F</td>
</tr>
</tbody>
</table>

Solids Temperature

Distance Along Kiln Axis (ft)

Gas Flow
Solids Flow
1147 ft³/min

Production | Firing Rate | Mud Solids | XS Air | Carbonate | Availability | Exit Temp
---|---|---|---|---|---|---
500 | 2400 | 100 | 50 | 25 | 100 | 1000
50 | 400 | 50 | 0 | 0 | 50 | 100
300tpd | 1147 ft³/min | 75% | 10% | 10% | 90.7% | 402°F

Solids Temperature

Distance Along Kiln Axis (ft)

Gas Flow

Solids Flow
1059 ft³/min

<table>
<thead>
<tr>
<th>Production</th>
<th>Firing Rate</th>
<th>Mud Solids</th>
<th>XS Air</th>
<th>Carbonate</th>
<th>Availability</th>
<th>Exit Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 tpd</td>
<td>1059 ft³/min</td>
<td>75%</td>
<td>10%</td>
<td>14%</td>
<td>90.7%</td>
<td>402°F</td>
</tr>
</tbody>
</table>

Solids Temperature

Distance Along Kiln Axis (ft)

Gas Flow

Solids Flow
Ranking of the Impact of Kiln Upsets on Ring Formation

Production >> Firing Rate > XS Air ≈ Mud Solids
Ring Formation

- As long as lime sludge kilns are required to produce nodules, rings will never go away, you can only minimize their impact on operation.
- To control ring growth:
  - Maintain total level of sodium below 0.75% (balance between mud washing and lime purge).
  - Minimize changes to production rate (every mill should develop a rate/surge strategy).
  - Maintain consistent product quality (constant level of residual carbonate).

Stability... Stability... Stability...
Lime Kiln Capacity Constraints

- There is no fixed upper limit to the capacity of the lime kiln itself. The production is limited by constraints on the peripheral equipment.
- There are nine major constraints on the production rate of a lime sludge kiln are:
  - Mud flow into the kiln - mud filter, conveyors and feed screws
  - Product flow out of the kiln - lump crusher, drag conveyors, bucket elevator and kiln drive
  - Gas flow out of the kiln - ID fan
  - Fuel flow into the kiln - fuel valve train, primary air fan and burner
  - Air flow into the kiln - firing hood and coolers
  - Materials temperature limits - metal shell, refractory surface, chains, ID fan and precipitator
  - Environmental emissions - particulate, NO$_x$ and TRS
  - Structural design - kiln shell, trunnions, tires and foundations
  - Operational problems - mud balls, poor nodulization and ring formation
- Ultimately the material temperature limits and operation problems play the most significant role in determining the maximum capacity for most kilns.
Examples of Lime Kiln Problem Solving
Original Pillard Burner at Longview

Pillard Burner

- High momentum burner (CC = 6.65)
- Short flame slightly pushed to the left side of the kiln (looking from the front-end)
- Large amount of recirculation
- No impact from NCG stream
- Corrected flame length is 41 ft
- Recommend replacing Pillard burner
Optimized KFS OPTIMIX Burner

KFS Burner

- Lower momentum burner (CC=2.5)
- More stable flame envelope
- No impact from NCG stream
- Good entrainment of NCG stream
- Corrected flame length is 64 ft
CFD Model of Longview Lime Kiln

Satellite Coolers and Lime Kiln
Non-Uniform Flow From Cooler

Velocity Vectors on a Cross Section at Z=1.5m

Air From Cooler

Velocity Distribution Across Cooler
Effect of Swirling Secondary Air

Swirling Secondary Air

Non-Swirling Secondary Air
Pine Hill Acid/Alkali Modeling of Existing Burner

- Natural gas firing
- Flame deflected toward the left and top of the kiln
- NCG has no effect on the flame View
Improved Kiln Hood Aerodynamics

Hood Modifications:
- Open rear kiln seals
- New opening around burner (8” gap)
- Top door closed
- Bottom door open
- Discharge chute closed

Design Parameters:
- Natural Gas
  - CC=2.65
  - FL=69 ft
- Oil:
  - CC=2.44
  - FL=63 ft

Secondary Air Supply

Fully Open Kiln Seal
Top Door on Hood
Bottom Door Next to Grate
Discharge Chute

New Opening Around Burner
New Bern Acid/Alkali Modeling

New KFS Burner
- CC=2.18
- Good flow patterns
- No flame impingement
- Corrected flame length = 65 ft

Existing Ring Formation
- 140 ft
- 50-60 ft
Flash Dryer Layout at Kamloops

Flash Dryer Section

- Wet Mud From Filter
- Flash Dryer
- Cyclone
- Fan
- Recycled Flue Gas
- Dry Solids
- Exit Gas
- Kiln
- Dust to Scrubber
The capacity rating for flash dryers is set by the exit gas temperature from the kiln. Above 1200°F the sodium in the mud particles form liquids that stick to the walls of the kiln and flash dryer. At these temperatures the dryer can plug in a matter of hours forcing the kiln to be shutdown for cleaning. This mechanism is similar to the way soda balls form on kiln chain (ring type 5 in slide #17).
Current Operation at Kamloops Using FEE Minerals Flash Dryer

Production 354 tons/day, Mud Solids = 90%, XS Air 1.8% (wet basis)

7.17 MMBtu/ton CaO

Gas Flow
Solids Flow

Discharge End     Feed End
Validation of Computer Model - Measured vs. Predicted Heat Balances

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat In:</strong></td>
<td>(MMBtu/hr)</td>
<td>(MMBtu/hr)</td>
</tr>
<tr>
<td>Sensible in Mud Feed</td>
<td>0.56</td>
<td>0.79</td>
</tr>
<tr>
<td>Sensible in Combustion Air</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Sensible in Fuel</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Sensible in NCG's</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Sensible in NCG Purge</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Heat of Combustion*</td>
<td>100.56</td>
<td>97.63</td>
</tr>
<tr>
<td>Total</td>
<td>101.65</td>
<td>98.42</td>
</tr>
</tbody>
</table>

| **Heat Out:**    | (MMBtu/hr)            | (MMBtu/hr)                      |
| Sensible in Kiln Product | 8.89                  | 9.82                            |
| Sensible in Exit Drier  | 21.90                 | 22.71                           |
| Sensible in Dust     | 0.86                   |                                 |
| Calcination         | 39.02                  | 34.58                           |
| Drying             | 7.15                   | 5.51                            |
| Hydrogen Loss       | 8.99                   | 9.59                            |
| Shell Loss          | 15.64                  | 16.21                           |
| Unaccounted        | -0.80                  |                                 |
| Total              | 101.65                 | 98.42                           |

* The heating value is given on a gross basis.
Validation of Computer Model - Measured vs. Predicted Mass Balance

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass In:</strong></td>
<td>(ton/hr)</td>
<td>(ton/hr)</td>
</tr>
<tr>
<td>Mud Feed</td>
<td>30.69</td>
<td>28.28</td>
</tr>
<tr>
<td>Combustion Air</td>
<td>42.10</td>
<td>40.67</td>
</tr>
<tr>
<td>Fuel</td>
<td>2.24</td>
<td>2.06</td>
</tr>
<tr>
<td>NCG’s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NCG Purge Air</td>
<td>1.87</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>76.90</td>
<td>71.01</td>
</tr>
<tr>
<td><strong>Mass Out:</strong></td>
<td>(ton/hr)</td>
<td>(ton/hr)</td>
</tr>
<tr>
<td>Kiln Product</td>
<td>14.75</td>
<td>14.75</td>
</tr>
<tr>
<td>Exit Gas from Drier</td>
<td>60.80</td>
<td>56.26</td>
</tr>
<tr>
<td>Kiln Dust</td>
<td>1.35</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>76.90</td>
<td>71.01</td>
</tr>
</tbody>
</table>

The computer predictions agree with the measurements made by KFS in September of 2002.
Options Considered for Increasing the Capacity Rating of the Kamloops Kiln and Flash Dryer System

The following options were considered in this study:

1. Original Kiln (No Dryer, 70% Mud Solids, Natural Gas)
2. Flash Dryer (90% Mud Solids, Natural Gas)
3. Flash Dryer (70% Mud Solids, Natural Gas)
4. Flash dryer (70% Mud Solids, Oil)
5. Flash Dryer (70% Mud Solids, Natural Gas, Dam)
6. Flash Dryer (70% Mud Solids, Oil, Dam)
7. Flash Dryer (70% Mud Solids, Natural Gas, Dam, Coolers)
8. Flash Dryer (70% Mud Solids, Oil, Dam, Coolers)
Effect of Operating Conditions and Kiln Geometry on Kiln/Dryer Performance

![Bar Chart]

Production (tons/day)
Heat Rate (MMBtu/ton CaO)

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Production Rate</th>
<th>Heat Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Original Kiln (No Dryer, 70% Mud Solids, Nat Gas)</td>
<td>335</td>
<td>7.54</td>
</tr>
<tr>
<td>2</td>
<td>Mud Dryer (90% Mud Solids, Nat Gas)</td>
<td>354</td>
<td>7.17</td>
</tr>
<tr>
<td>3</td>
<td>Mud Dryer (70% Mud Solids, Nat Gas)</td>
<td>400</td>
<td>7.45</td>
</tr>
<tr>
<td>4</td>
<td>Mud Dryer (70% Mud Solids, Oil)</td>
<td>470</td>
<td>6.59</td>
</tr>
<tr>
<td>5</td>
<td>Mud Dryer (70% Mud Solids, Nat Gas, Dam)</td>
<td>405</td>
<td>7.25</td>
</tr>
<tr>
<td>6</td>
<td>Mud Dryer (70% Mud Solids, Oil, Dam)</td>
<td>475</td>
<td>6.54</td>
</tr>
<tr>
<td>7</td>
<td>Mud Dryer (70% Mud Solids, Nat Gas, Dam, Coolers)</td>
<td>470</td>
<td>6.31</td>
</tr>
<tr>
<td>8</td>
<td>Mud Dryer (70% Mud Solids, Oil, Dam, Coolers)</td>
<td>550</td>
<td>5.8</td>
</tr>
</tbody>
</table>
Effect of Operating Conditions and Kiln Geometry on Exit Gas Temperatures

1. Original Kiln (No Dryer, 70% Mud Solids, Nat Gas)
2. Mud Dryer (90% Mud Solids, Nat Gas)
3. Mud Dryer (70% Mud Solids, Nat Gas)
4. Mud dryer (70% Mud Solids, Oil)
5. Mud Dryer (70% Mud Solids, Nat Gas, Dam)
6. Mud Dryer (70% Mud Solids, Oil, Dam)
7. Mud Dryer (70% Mud Solids, Nat Gas, Dam, Coolers)
8. Mud dryer (70% Mud Solids, Oil, Dam, Coolers)
Ranking of Options Used to Increase the Capacity of the Kamloops Kiln and Flash Dryer System

- The original capacity rating for the Kamloops kiln was around 335 tons/day with a fuel consumption of 7.54 MMBtu/ton of CaO. Originally, the kiln was sized for a mud solids content of 70%. Around 7000ft² of chain would have used at the time the kiln was built.
- The capacity rating after removing the chain and installing the flash dyer was estimated by FFE Minerals to be around 560 tons/day. In their calculations they used a mud solids content of 70%.
- The mud solids content off the new filter is currently over 90%. As a result, the kiln and flash dryer system is only able to produce around 354 tons/day with a fuel consumption of 7.17 MMBtu/ton CaO. As previously described, the high temperatures entering the flash dryer and entering the ID fan constrain the capacity of the system. The addition of a flash dryer only increased the production of lime by 20 tons/day.
- Due to the sizing of the throat in the flash dryer, at the current production levels, a large amount of recycled flue gas is required to entrain all of the mud being fed to the kiln. The throat in the flash dryer is oversized.
- Decreasing the mud solids to 70% would increase lime production to 400 tons/day with a fuel consumption of 7.14 MMBtu/ton of CaO. This is a small energy penalty for increasing production.
Ranking of Options Used to Increase the Capacity of the Kamloops Kiln and Flash Dryer System (con’t)

- Firing the kiln with oil at a mud solids content of 70% would further increase the lime production to 470 tons/day with a fuel consumption of 6.59 MMBtu/ton CaO. Oil is a better fuel than natural gas. The higher flame emissivities combined lower combustion air requirements reduces both the fuel consumption and exit gas temperatures. The lower temperatures leaving the kiln translate into increased lime production.

- Installing a discharge dam results in only a small increase the production rates for both natural gas and oil. The big advantages of a discharge dam are:
  - Lower refractory temperatures in the burning zone of the kiln
  - More consistent product quality
  - The large chunks will spend more time in the kiln giving them more chance to break apart
  - Allows for the installation of a rotating grizzly (installing a rotary grizzly with no other changes would most likely eliminate the need for shooting chucks inside the kiln and firing hood)

- Decreasing the mud solids content in combination with installing product coolers offers another large increase in lime production. For natural gas, retrofitting a product cooler would increase the lime production to 470 tons/day. For oil, the lime production would be increased to 550 tons/day. In both cases, installing product cooler decreases the exit gas temperature. The production levels with a cooler are very close to the capacity rating originally given by FFE Minerals.