

LIME KILN EQUIPMENT, OPERATION AND MAINTENANCE

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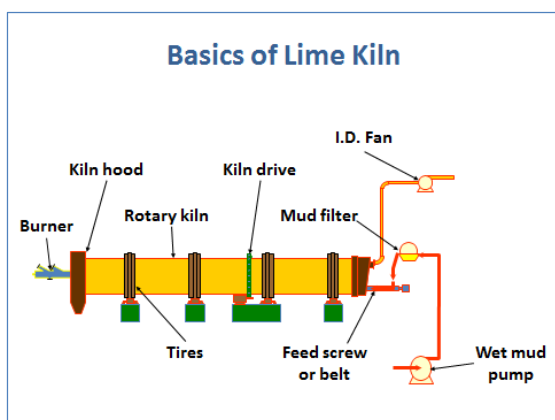
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INTRODUCTION

This paper presents some further information on the internals, potential for operational & efficiency improvements and general maintenance aspects of the lime kiln.

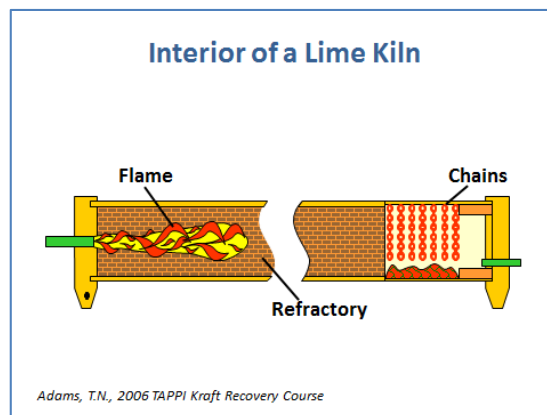
Continuing the overall topics related to the lime kiln, we will move first to kiln internals; chain system and refractory. Discussion will include design concepts, materials and operation. Concentration will turn to typical operations and presentation of data from a “benchmark kiln” that will allow us to illustrate potential for improvement in overall kiln efficiency via operational adjustments &/or retrofits. The closing section will cover general maintenance to increase overall lime kiln reliability.

The slide below depicts a generalized schematic of the exterior of a common rotary lime kiln. More information on external maintenance of the kiln appears later in this paper where some items shown will be discussed in more detail.



LIME KILN INTERNALS

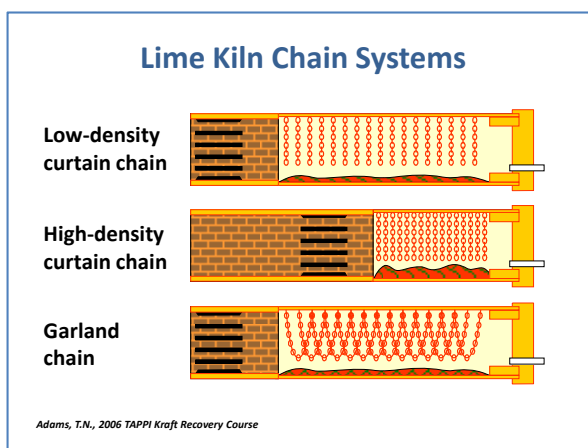
Basic layout of kiln internals is shown below.

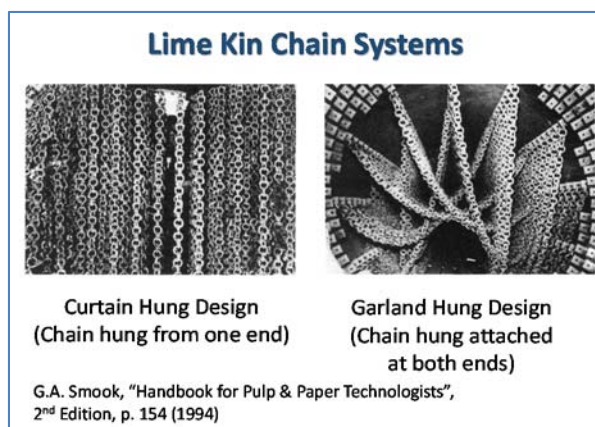


LIME RECOVERY KILN CHAIN SYSTEMS

Note that chain systems are typically not installed in lime kilns equipped with external dryers.

At the cold end of the kiln, to promote heat transfer from the gas stream to the feed material, thereby increasing efficiency, chain is hung from the shell. This chain is made up of links that are typically $\frac{3}{4}$ in. by 3 in. (1.9 cm x 7.6 cm). Hangers attach lengths of this chain directly to the kiln shell either from one end or both ends. When chain is hung from one end it is referred to as curtain chain, when hung from both ends it is called a garland system. The slide below shows sketches of these two types of chain systems, and shows the difference between high-density and low-density chain hanging arrangements. Also included are photographs of the two types of chain systems, one with curtain-hung chain and one with “garland” chain.





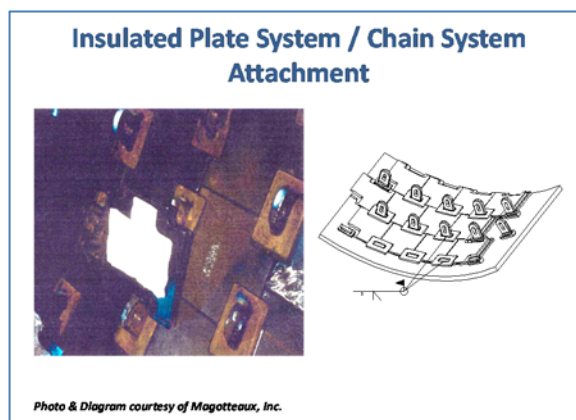
The photo below offers detail of a current type of chain hanging arrangement. The major loss of chain from a kiln is often failure of the hangers, which are welded to the kiln shell. The hanger welds are alternatively exposed to heating and cooling about once-per-minute. This stress causes the poorer welds to fail. Chains are typically attached to the hangers by a shackle with a fully welded pin but nut & bolt that are welded to prevent failure are more often used to increase reliability. Newer designs have a hanger "base" that is designed to have a "cap" slid onto them which acts as the shackle; these are secured with welded nut & bolt. The cap/base design allows the chain to hang more freely as the kiln rotates without hanging up on the larger nut used on conventional shackles.



The pictures above & below depict the most "current" chain system hanging and shell insulation/protection designs. Besides chain loss, castable refractory loss has also been a historical recurring maintenance issue. As the chain system exchanges heat the material and gas stream temperatures reach levels which could damage the mild steel kiln shell if not protected by refractory or another means of insulation/protection.

Plates about 1-foot square are secured in place by direct welding to the hangers or by means of welding a "fixation plate" to the hanger which holds the plate in the kiln but allows for the constant expansion/contraction that takes place. The plates are set up off the shell to create a gap between the plates and the kiln shell. This creates an air space that reduces heat loss from this section, and insulation can be added to these spaces to further reduce heat loss. Hangers are directly welded to the kiln shell and protrude through the plates to form a strong base for mechanical attachment of the hangers, making a more robust chain attachment system. The above photo also shows the chain links themselves have a different cross-section in order to increase heat transfer surface area.

Below is shown an insulated plate and chain hanging system that utilizes "fixation plates" rather than direct welding to the hangers. This design relieves some of the stress on the hangers increasing their reliability. The plates have an interlocking design which results in the plates remaining in the kiln even if there is a hanger failure.



The pattern and resulting "density", square feet of chain surface area per cubic feet of kiln volume, in which a chain system is hung is determined by the spacing of the chain hangers and the number of chains hung per hanger. Typical chain system density is measured as square feet of surface area per cubic foot of kiln volume and ranges from 2 ft.²/ft.³ to 4 ft.²/ft.³ with the more dense zones dedicated to assist in dust loss reduction and heat protection. A dense zone is often found near the feed/cold end of the chain system to allow the dust particles in the gas stream to impact and settle as well as become attached to the moist chains, this aids in reducing the dust loss from the kiln. At the discharge/hot end of the chain system, the higher density acts as a "heat shield" to better withstand the higher temperatures and protect the rest

of the chain system. In most cases, the chain hanger pattern layout forms a series of spirals designed to encourage the flow of material through the chain system, down the kiln.

In general the typical industry standard for overall quantity of chain in a modern lime kiln is 40 lineal hanging feet of standard 3/4" x 3" link chain per ton per day of total kiln product or 240 lbs. of chain per ton per day of total kiln product.

The method of hanging the chain makes little difference in its effectiveness as a regenerative heat exchange surface, though other aspects of chain performance are affected by installation and arrangement. As long as the chain alternatively contacts the combustion gases and the lime mud as the kiln rotates, it is effective. Like any low-temperature heat exchanger, it is the available surface area that is most important to effectiveness. The chain surface area in a lime recovery kiln can represent two-thirds of the entire heat transfer surface. Due to this contribution to the overall efficiency of the kiln system, it is important that a proper sized and designed chain system is installed in the kiln and maintained over time to assure its continued effective performance.

Chain system design must complement the kiln geometry, average mud feed moisture and average production rate. Installation of too much chain &/or extended operation at lower feed/production rates can result in the build-up of material onto & within the chain system. The photos below offer examples of a kiln operated in an "overchained" condition.



A final component of most chain system designs is a series of "feed spirals". These are formed by rows of mild steel plate, bent in segments to set against the kiln shell while forming a continuing spiral pattern. The feed spirals motivate the feed material away from the

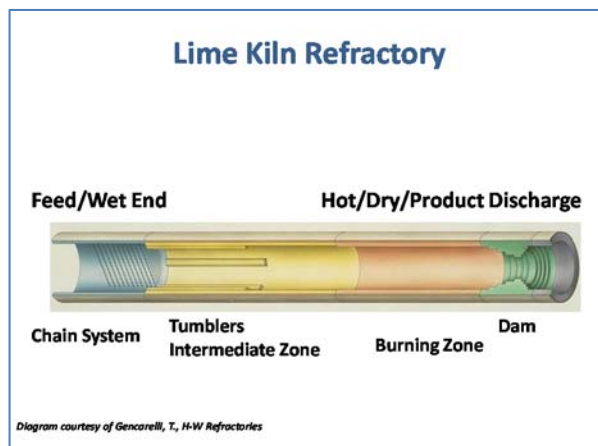
feed/cold end of the kiln and down into the chain system. Typically 4 to 6 rows are used set at an approximate 30° angle to the feed end, height is typically calculated to assure the spirals are beyond the depth of the bed at maximum feed rate to assure their effectiveness. Below is shown a set of feed spirals looking into the feed end of a high density chain system zone, designed for dust loss suppression.



The most significant drawback of chain systems is the required maintenance. Similar to the reasons for proper design, a chain system must be maintained to retain maximum efficiency.

LIME KILN REFRACTORY SYSTEMS

There are several different types of refractory materials available for application in lime reburning, and usually two or three of these are used at different locations along the length of the kiln. A very common refractory system consists of bricks that are either shaped to fit the curvature of the shell, Rotary Kiln Brick (RKB) or are in thinner combination wedges/shapes that can be laid in an arch pattern in order to produce a complete shell lining. Below is a slide showing typical refractory layout in a lime kiln.



The refractory bricks are composed of special heat-resistant and chemical-attack resistant materials that are most often alumina and silica compounds. Selection of refractory is based on the temperatures and potential for chemical reaction with feed materials in the zone they are to be installed. To increase efficiency, working linings can be installed with an underlying or back-up insulating layer, so called dual component or two-brick lining.

From the cold or feed end; a stainless steel needle reinforced, castable, lower-temperature refractory is used in the chain section or feed zone of an external dryer equipped unit. In lime kilns with chain systems, feed spiral zones and extending 15-20' (4.5-6m) downhill are typically unlined. Chain system refractory is often replaced with one of the insulated steel plate systems, which hold up better under the constant battering of the chains and cycling temperatures.

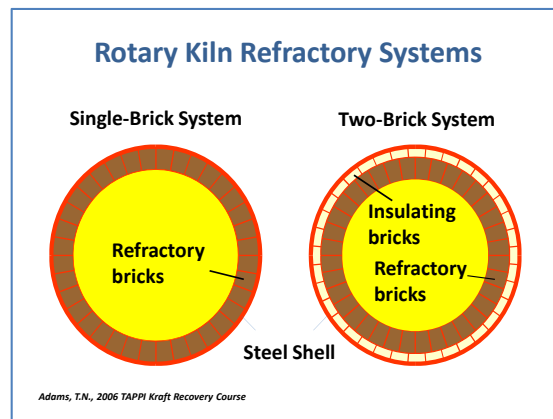
Downhill of the chain system or feed zone and uphill of the burning zone, about one-third of the way up the length of the kiln from the discharge end is the intermediate or pre-heating zone. Temperatures range from 1375-1700°F (750-925°C), at which little chemical interaction takes place. Typically a 6.0" (155mm) 40-60% alumina refractory is used as the working or hot face lining. A dual layer lining can be used, normally 2.5" (65mm) diatomaceous earth refractories as the underlayment. For easier installation 9" (220mm) single layer combination (working lining/insulation) fire clay type bricks are now often being utilized.

Refractory in the burning zone of the kiln near the flame are composed of 60-70% alumina materials in order to resist the high temperatures (1750-2100°F(950-1150°C)) and chemical attack in this region. A dual layer lining can be used, normally 1.5" (50mm) diatomaceous earth or fire clay refractories as the underlayment.

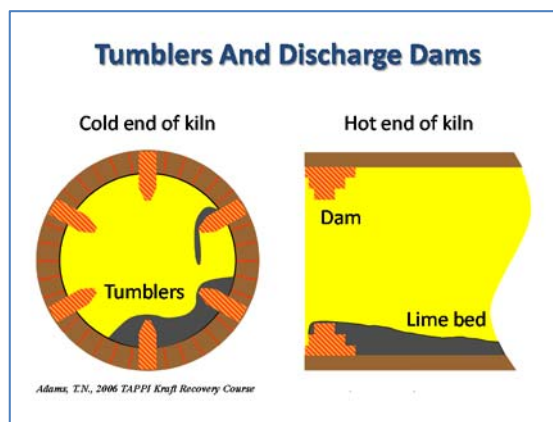
A single 9" (220mm) layer of "basic" or magnesia/alumina refractory can be utilized. Basic brick is far less chemically reactive in high temperature alkali conditions but is denser and heavier increasing thermal conductivity decreasing thermal efficiency. The high density also makes it more difficult to utilize a back-up insulating layer.

Many modifications of this pattern are now available including cast or packed refractories in place of bricks, or two-brick systems that use insulating bricks against the steel shell and chemical-attack resistant bricks in contact with the lime solids and combustion gases.

Diagram below shows the arrangement for a single-brick and a two-brick refractory system.



Shown below are two other features of the interior lining of rotary kilns that are used to improve heat transfer.



The first feature is a set of tumblers that are installed in the cold end of the kiln, usually just downhill from the chains.

Tumblers mix the lime mud and expose it to the hot gases. Design of these systems should be such that the material cascades off of chamfered edges at about the 4:00 or 8:00 position (dependent on kiln rotational direction) as the kiln rotates. This design mixes and turns the bed to increase the rate of heat transfer. A tumbler zone should not be designed to act like a "lifter" zone raising the material higher in the kiln and showering it into the gas stream as this would promote increased dust losses in the exit gas stream.

Discharge dams are usually located at the hot end of the kiln and cause the lime to pool behind the dam underneath the flame. This design creates a wider, deeper bed of material to aid in protecting the

refractory lining. It also adds additional retention time in the kiln for the material to become fully calcined. Discharge end dam design is important to allow for a dam high enough to gain the desired benefits but low enough to avoid adverse effects to the process operations. Typical dam height is 50-70% of the base refractory internal diameter of the surrounding lining but should be checked to avoid excessive pressure drop and/or velocity of the gas stream through the dam area.

The ability of the refractory lining to withstand chemical attack by the lime and its constituents is crucial to the service life of this part of the kiln. Although sudden changes in temperature can damage the lining, it is primarily due to chemical attack that refractory is washed from the kiln and requires periodic replacement. Quite aside from the increased heat loss associated with thin, worn refractory lining, it is important for structural reasons to maintain the lining to avoid exposure of the steel shell to combustion temperatures.

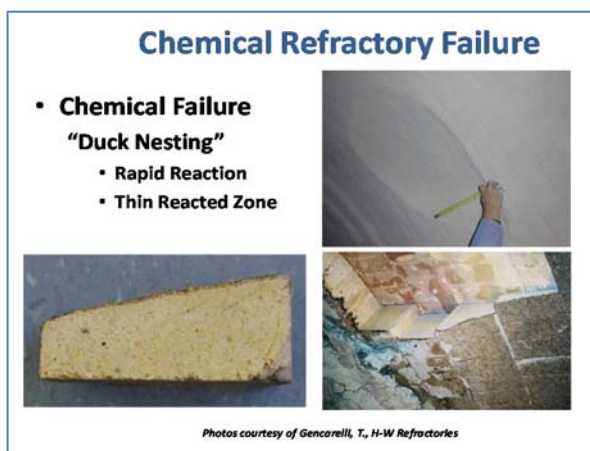
Photos below show refractory wastage and resulting refractory collapse, when the arch effect of the bricks is lost and several complete rows of bricks fall out. If not addressed promptly the kiln shell can overheat and deform. Severe shell deformation requires replacement of the affected kiln section.



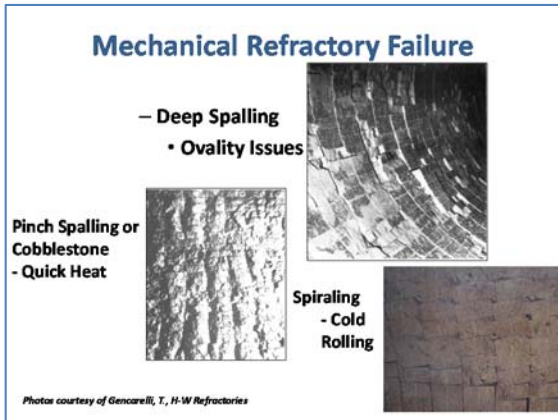
Refractory failures in lime kilns can occur due to chemical interaction which rapidly degrades the lining or by mechanical actions that physically break up the brick.

For high alumina bricks, starting around 2642°F (1450°C) sodium compounds and other impurities in the mud begin to react with the alumina (Al_2O_3) and silica (SiO_2) in the bricks to form liquids with their behavior dependent on the raw materials from which

the bricks were manufactured. Calcined bauxitic ores consisting mainly of corundum ($\alpha\text{-Al}_2\text{O}_3$) are generally used to produce 70% alumina bricks. Presence of corundum in these bricks lowers the viscosity of the liquids formed at high temperatures allowing them to readily penetrate into the matrix of the brick leading to rapid failure of the lining. Andalusite or sillimanite are often used as the starting material to produce 60% alumina bricks. During the manufacturing process these materials react to form mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$). As such, 60% alumina bricks made from these starting materials contain no detectable corundum and the liquids that form at high temperatures are more viscous causing them to stay on or close to the surface of the brick forming a protective layer that retards the reaction of alkali compounds in the mud with the brick. In all cases, continuous operation above 2732°F (1500°C) can result in premature failure of the high alumina refractory linings. Photos below show brick samples with evidence of chemical reaction caused by localized overheating, smelting (liquid formation) and subsequent wash out or “duck-nesting” of the lining.



Examples of typical mechanical failure of refractory are shown below. Deep spalling, capping or crushing of the outer tips of refractory bricks normally occurs near the kiln piers. Kiln ovality is the degree to which the shell loses its cylindricity and runs in an oval type shape as the kiln rotates. If uncontrolled, this cyclic flexing action places excessive pressure at the tips of the bricks breaking them off. Further definition, measurement & remedy of ovality concerns are covered later in this paper.



Pinch spalling or “cobblestone” wear is typically caused by rapid heating of the kiln. Time must be given during the re-heat of the lime kiln after a shutdown so that the heat can soak through the refractory, kiln shell and other components. This longer heat soak (typically defined in OEM & refractory supplier heat-up curves) allows all of the components to expand into place as designed. If heated too quickly the kiln shell does not expand sufficiently to accept the refractory expansion and the pinch spalling occurs.

When the kiln is fully cooled and the shell and refractory are fully shrunk, the lining is actually slightly loose. Excessive rotation of the kiln should be avoided to prevent shifting or “spiraling” of the lining.

Any of the above described mechanical activities, if the resulting damage becomes excessive, the lining can loosen and prematurely fail.

IMPROVING EFFICIENCY

Kiln production and efficiency is summarized in the slide below. Production is increased with modification to kiln design and internals. Fuel economy also improves with these modifications.

Kiln Production and Efficiency
(At 76% Feed Solids)

System Type	Production Factor (ft ³ /stpd)	Relative Heat Rate (MMBtu/st CaO)	Electric Power Consumption (kWh/st)
Older conventional long kiln	100+	9.0	67.0+
Long kiln retrofitted With high efficiency internals	73-78	8.4	63.0
New long kiln with high efficiency internals, product cooler & ESP	70-75	7.3	45.0
External dryer equipped system with high efficiency internals, product cooler & ESP	55-60	7.6	50

To assist in explaining heat consumption in a lime kiln and offer comparisons based on operational changes and retrofits designed to increase efficiency; we developed a “Benchmark Kiln” heat/mass balance. See below for our initial data

Benchmark Kiln

• With no coolers, no cyclone and no precipitator

Parameter	Units	Base
Production total	tpd	250
Production CaO	tpd	213
Wet mud feed rate	gpm	270
Dust loss	tpd	91
Mud dry solids	% wt	73%
Lime availability	% wt	85%
Natural gas	kscfh	78.6
Oil	gpm	0.0
Feed-end O ₂	% vol wet	3.0%
Feed-end temperature	°F	550
Product temperature	°F	1800
Shell loss	MMBtu/h	11.3
SFC - CaO	MMBtu/t	9.6
Total Heat Release	MMBtu/h	76.9

Manning, R.P. - 2014

Caution needs to be taken with heat rate calculations as these provide instantaneous values assuming steady state operation and do not account for significant process upsets so they may underestimate the actual heat rate for the kiln at any given time or over the long term.

To understand our goals please note the following regarding lime kiln heat rate;

- Heat rate is a measure of energy efficiency
 - Units are MMBtu/ton CaO or GJ/tonne CaO
 - Often stated as MMBtu/ton CaO
- Typical heat rate range
 - 7.3 to 10 MMBtu/ton CaO
 - 8.4 to 11.6 GJ/tonne CaO
 - Lower is better

As we dissect our benchmark data, we can look at specific heat rate consumptions for various activities and assign potential actions to increase efficiency.

Lime Kiln Heat Rate			
• Overall Heat Rate = 9.6 MMBtu/ton CaO			
Contribution	Heat Rate	Fraction	Remedy
Calcination	3.1	32%	Not possible
Drying	2.1	21%	Increase mud solids
Exit Gas	1.9	20%	Lower exit gas temp.
Shell Losses	1.4	15%	Insulating refractory
Products	1.0	11%	Product coolers
Dust	0.1	1%	Improve chain system

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34% of the heat goes directly to the work of the kiln, calcining lime and as such is required to get the desired product quality.

Significant heat is used to evaporate the remaining water in the mud feed. Increasing the solids level, reducing the water content will reduce this rate. Note however that solids rates above 80% in chain system kilns present diminishing beneficial reductions as dust loss increases and exit temperature rises.

Exit gas heat losses can be controlled through excess oxygen management. Kiln excess oxygen needs only be sufficient to fully combust fuels and oxidize foul gases; any excess oxygen serves as a heat sink and reduced efficiency.

Heat passes out through the kiln shell; control of these losses through the use of insulating refractories can improve kiln efficiency.

The most common fuels used in lime kilns are natural gas and fuel oil as they are readily available. Fuel oil is more efficient in terms of heat transfer and typically results in higher kiln capacity.

Natural gas is easier to use and currently cheaper. Natural gas burns with significantly less luminosity resulting in poorer radiation and flatter heat flux profile along the kiln starting further from the kiln discharge effectively shortening the kiln.

Commercially used liquid fuels range from gas (diesel) oil through to heavy fuel oil. The liquid fuels are atomized to create a spray of tiny droplets. Combustion takes place in the vapor phase around the droplets before being finally burned at the surface of

the remaining fuel creating a very visible and luminous flame and high radiant heat transfer.

Heat that is lost with the product can be recovered via the addition of product coolers. However, due to the added overhung weight of product coolers and typically inadequate room for them to be installed in an existing kiln configuration, this retrofit is very rare on existing kilns but is standard on new kiln systems.

Heat lost with dust has some impact and may be improved with optimized kiln operations to reduce overall process gas flows and optimization of the chain system to capture entrained dust and return it.

Note that changes in some of the parameters affect more than one of the loss terms, so experience and judgment are needed to interpret the results. Some changes that can have significant impacts on overall energy consumption at the kiln, for example:

- changes in refractory affect shell losses and exit gas temperature
- mud moisture affects evaporation energy losses and exit gas temperature

So we will look at some examples of potential major improvements;

Major Heat Rate Improvements (1)					
Parameter	Units	Base	Coolers	Dry solids	Cyclone
Production total	tpd	250	250	250	250
Production CaO	tpd	213	213	213	213
Wet mud feed rate	gpm	270	270	270	235
Dust loss	tpd	91	91	91	25
Mud dry solids	% wt	73%	73%	78%	73%
Lime availability	% wt	85%	85%	85%	85%
Natural gas	kscfh	78.6	71.1	72.9	74.8
Oil	gpm	0.0	0.0	0.0	0.0
Feed-end O ₂	% vol wet	3.0%	3.0%	3.0%	3.0%
Feed-end temperature	°F	550	550	550	550
Product temperature	°F	1800	535	1800	1800
Shell loss	MMBtu/h	11.3	11.3	11.3	11.3
SFC - CaO	MMBtu/t	9.6	8.7	8.9	9.1
Total Heat Release	MMBtu/h	76.9	69.6	71.4	73.2
Savings			9.6%	7.2%	4.8%

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As shown on our Benchmark Kiln;

- Addition of product coolers would return heat to the kiln thereby reducing the required fuel.
- Increasing the lime mud feed solids reduces the heat required to evaporate moisture and thus reduces the required fuel input.
- Adding a dry dust collector system (cyclone or multiple tube type) returns feed lost as dust, dried and preheated reducing the heat required to evaporate moisture and thus reduces the required fuel input. An additional benefit is increased kiln production at the

same previous feed rate as more material is making into the kiln and coming out as product.

Continuing with specific changes to improve efficiency;

Major Heat Rate Improvements (2)

Parameter	Units	Base	Refractory	Oil
Production total	tpd	250	250	250
Production CaO	tpd	213	213	213
Wet mud feed rate	gpm	270	270	270
Dust loss	tpd	91	91	91
Mud dry solids	% wt	73%	73%	73%
Lime availability	% wt	85%	85%	85%
Natural gas	kscfh	78.6	75.4	0
Oil	gpm	0.0	0.0	6.3
Feed-end O ₂	% vol wet	3.0%	3.0%	3.0%
Feed-end temperature	°F	550	550	450
Product temperature	°F	1800	1800	1800
Shell loss	MMBtu/h	11.3	8.5	11.3
SFC - CaO	MMBtu/t	9.6	9.2	8.8
Total Heat Release	MMBtu/h	76.9	73.8	72.4
Savings			4.1%	5.9%

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- Adding insulated refractory reduces kiln shell heat losses thereby reducing the required fuel input to achieve the same results
- Switching from natural gas to fuel oil with its' higher luminosity, radiant heat transfer and steeper heat flux profile reduces the overall heat input and results in lower exit gas temperatures

In summarizing the concepts & improvements shown above, the project list below could be applied but as noted, typically these are higher, more long-term projects.

- Longer Term /Higher Capital Projects
 - Improve refractory system (Insulation)
 - Switch fuels
 - Improve chain system
 - Optimize &/or change burner
 - Kiln control system
 - Install dry dust collection/return system

Addition of high level control system can offer benefits. Modern or advanced control systems add to kiln efficiency by stabilizing kiln operations. Current designs utilize advanced control logic which allows the control system to monitor and make changes in a more constant and effective rate than an operator can. This is not to say that the operator is not needed as control systems typically cannot be initiated until operations are within a “normal” operating range and in many cases cannot respond to dramatic upset conditions. But control systems can check multiple data points and make appropriate control adjustments on a more frequent and prompt basis. As noted in previous

discussions, kiln process operations stability can aid significantly in avoiding kiln internal build-ups and also typically results in more efficient operations.

The addition of a dry dust collection & return system can offer significant benefits to existing kilns equipped with wet particulate scrubbers. Primary equipment is a single stage cyclone or a multiple tube type dust collector. Either can be used between the kiln feed end and the inlet to the I.D. fan. The dry dust is collected and returned to the mud feed screw or directly into the kiln. Benefits include the reduced particulate loading of the scrubber and mud systems leading to, decreased scrubber bleed and make-up rates and reduced I.D. fan build-up. These benefits increase efficiency though increased mud filter solids and increased kiln production at the same feed rates. See pictures below of lime kiln dust collection systems.

Dry Dust Collection/Return Installation



Multiple Tube Dust Collector



Single/Primary Cyclone

OPTIMIZING OPERATION

There are ways to increase lime kiln efficiency simply by optimizing current operations. Below is our Benchmark kiln with minor optimization benefits shown.

Minor Heat Rate Improvements

Parameter	Units	Base	Lime	O ₂
Production total	tpd	250	232	250
Production CaO	tpd	213	213	213
Wet mud feed rate	gpm	270	260	270
Dust loss	tpd	91	91	91
Mud dry solids	% wt	73%	73%	73%
Lime availability	% wt	85%	92%	85%
Natural gas	kscfh	78.6	77.2	76.7
Oil	gpm	0.0	0.0	0.0
Feed-end O ₂	% vol wet	3.0%	3.0%	2.0%
Feed-end temperature	°F	550	550	525
Product temperature	°F	1800	1800	1800
Shell loss	MMBtu/h	11.3	11.3	11.3
SFC - CaO	MMBtu/t	9.6	9.4	9.4
Total Heat Release	MMBtu/h	76.9	75.6	75.1
Savings			1.7%	2.4%

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As explained earlier, control of excess kiln oxygen (1.0 – 2.0% inside kiln feed end) reduces process gas flow and the heat carried with it.

Establishing a target residual carbonate level offers benefits. Typically a level of 1.0-3.0% represents product that is sufficiently burned and converted but not overburned. Going beyond the target level wastes fuel and results in kiln operation closer to overheating conditions. Establish a residual carbonate level that provides for good reaction and settling in the recaust system. Manual tests need to be run regularly and the results reported promptly to the operator to allow adjustments to be made if needed.

Periodic testing of lime availability (lime availability = 100% - residual carbonate – inerts) is important but does not directly impact immediate kiln operations. But as depicted below, increasing and maintaining lime availability can increase efficiency. Inerts are non-process elements such as silica, aluminum & iron; they have no participation in the chemical processes but are along for the ride through the kiln and must be heated to calcining temperature to produce the desired residual carbonate level in the kiln product. There is not an economically efficient means to easily separate the inerts from the lime. The best way to increase and maintain lime availability is to purge low available lime mud from the system through increased dregs precoating and/or dumping mud. A certain level of fresh make-up lime will be needed to increase and maintain the overall lime availability.

A view of our Benchmark Kiln, Optimized;

Optimized			
Parameter	Units	Base	Optimize
Production total	tpd	250	232
Production CaO	tpd	213	213
Wet mud feed rate	gpm	270	260
Dust loss	tpd	91	91
Mud dry solids	% wt	73%	78%
Lime availability	% wt	85%	92%
Natural gas	kscfh	78.6	69.0
Oil	gpm	0.0	0.0
Feed-end O ₂	% vol wet	3.0%	2.0%
Feed-end temperature	°F	550	525
Product temperature	°F	1800	1800
Shell loss	MMBtu/h	11.3	10.2
SFC - CaO	MMBtu/t	9.6	8.4
Total Heat Release	MMBtu/h	76.9	67.5
		Savings	12.2%

Manning, R.P. - 2014

Lime mud feed solids have been increased through optimized precoat filter operations. This results in a lower feed rate for the same production, less fuel/heat needed to evaporate moisture. Optimization of residual carbonate and lime availability levels increase

actual lime production and reduce fuel waste on inerts. Lower exit gas oxygen reduces process gas flow and waste heat. Lower overall heat input and temperatures result in lower shell heat loss. All the above allow for reduced fuel consumption. This optimization can be implemented without significant capital investment in a major retrofit.

The cases presented represent specific examples and will differ dependent on the existing configuration and condition of the kiln and auxiliary systems. It is possible that more or less dramatic effects may occur for each comparative case. An overall process and system evaluation needs to be done to determine which efficiency concepts will yield the maximum benefits for a given kiln system. Combinations of changes may offer significant increases in operating efficiency.

A listing of operating guidelines and cautions for upset conditions;

- Change Feed Rate Slowly
 - Change in Small Increments
 - 5% or 10GPM
 - Allow Kiln to Settle Down
 - Upsets DECREASE efficiency
 - Bad Lime = MORE Mud
- Avoid Large Changes in Kiln Draft
 - Effects Temperature Profile
- Maintain Constant Firing Rate
 - Adjust for Temperature Drifts / Feed Rate Changes
- Plan Ahead
 - Visualize Consequences of Change
 - React Accordingly and Incrementally
- Use EXTREME CAUTION during Heat-Up & Cool Down
 - Use OEM and refractory supplier schedules
 - Upset & holding conditions
 - Note and monitor conditions
 - Do NOT use shortcuts
 - Water introduction
 - Quick heat-Up
- These are the MOST common times when kiln damage occurs

During Upset conditions;

- Maintain kiln rotation to prevent shell distortion
- Prevent burning zone refractory from going above rated temperature
- Maintain Kiln burner(s) cooling or retract
- Prevent rapid refractory heat up or cool down
 - Cut draft if combustion system is off
- Limit exit gas temperature

GENERAL KILN MAINTENANCE CONCERNS

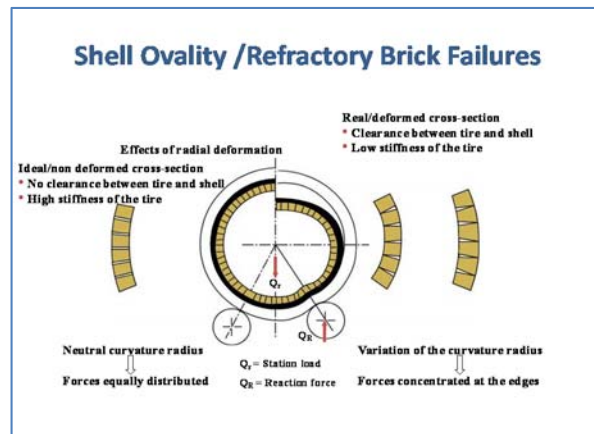
The most significant drawback of chain systems is the required maintenance. Similar to the reasons for proper design, a chain system must be maintained to retain maximum efficiency. Chain systems are often overlooked during shutdowns. A complete inspection should be done on each major shutdown. Losses in chain thickness and/or length equate to losses in available heat transfer surface area reducing kiln efficiency. Thin and short chains should be cut out and replaced to maintain the available heat transfer surface area.

The inspector should obtain the latest chain system drawing or compose a sketch which will delineate the materials, hanging pattern and definition of refractory &/or liner plates present. Using a set of tape measures, track position in the kiln from the feed end and relate to any zones on the drawing or sketch. Standard 3/4" chain can be checked for average thickness using a set of box end wrenches from 1/2" to 3/4" which will allow the inspector to determine if chain needs to be removed & replaced due to wear. Any missing, short or worn chains, refractory &/or liner plates should be replaced.

Monitoring refractory conditions is critical to protecting the kiln shell from significant damage. As refractory is installed, a comprehensive mapping record should be made to track types and quantities of refractories, original installed thickness, positions of brick retaining rings, all with corresponding dates of installation. During shutdowns refractory existing refractory lining thickness should be recorded and added to the master record. These records will assist in long-term planning for future shutdowns.

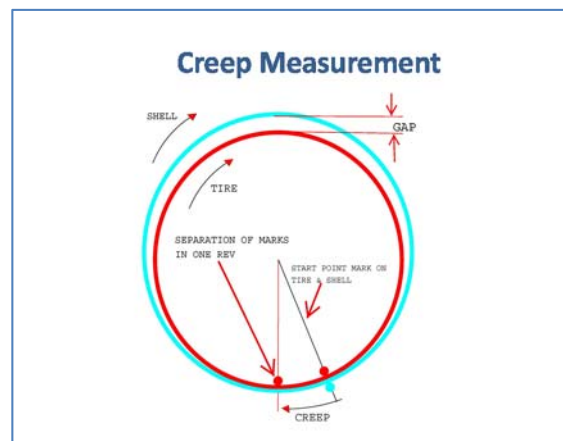
As a kiln is restarted and reaches normal operating load, temperatures and conditions, an initial thermal scan of the shell should be taken and recorded. At regular intervals thermal scans should be made and compared to the most recent initial restart record. This comparison will aid in identifying areas of build-up in the kiln &/or areas of high wear or potentially failed refractory. These scans can be done using handheld IR devices, a thermal imaging camera or a continuous shell scanner.

Refractory can be mechanically affected by high kiln shell ovality. Kiln ovality is the degree to which the shell loses its cylindricity and runs in an oval type shape as the kiln rotates. If uncontrolled, this cyclic flexing action places excessive pressure at the tips of the bricks breaking them off. See below for a graphic depiction



There is a proportional relationship between kiln shell ovality and tire “creep”;

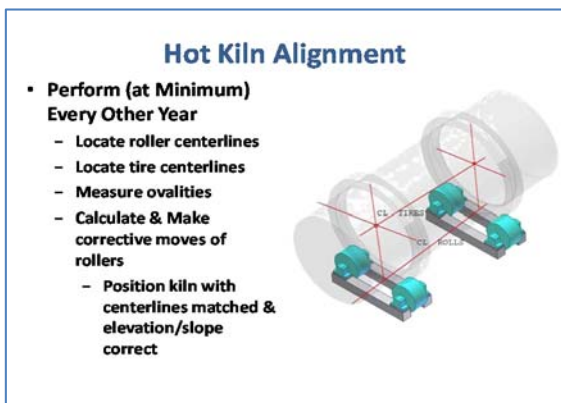
- “Gap” is the difference in diameters shell outer diameter (OD) and inner diameter (ID) of the tire
- The shell drives the tire, if the shell and tire had perfect traction (no slip) “CREEP” would be a function of difference between the circumference of the shell and the circumference of the tire for 1 revolution or $\pi (ID \text{ tire} - OD \text{ shell})$ $\pi = 3.1416$
- However, some slippage can occur therefore approximately $CREEP = 2.25 \times \text{the Gap}$, Example: $\text{Gap} = 0.125$ Creep = 0.28”
- The constant 2.25 is an average, a measured “hot” creep value of 1/4” to 3/8” is normal
- If the creep & hence gap become excessive, shell ovality increases along with cyclic flexing which can lead to refractory & possibly shell failures
- If the creep & hence gap is zero the tire and shell lockup & the shell may continue to expand into a permanent deformation or “Coke-bottle” condition requiring shell replacement.



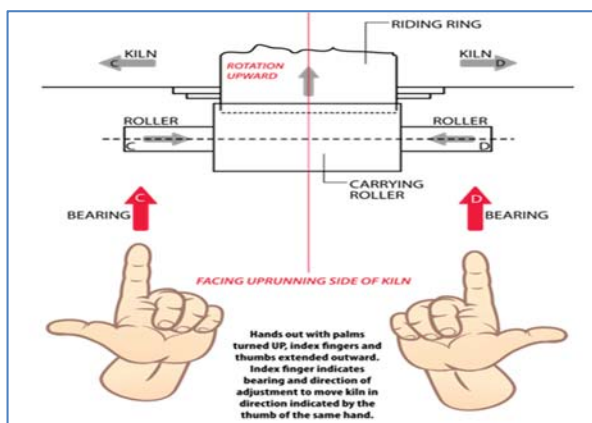
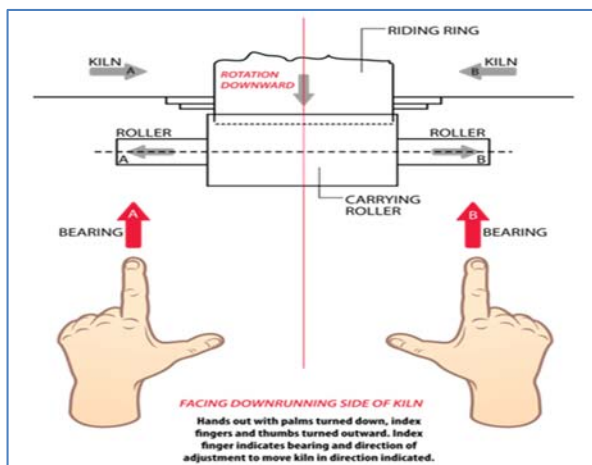
Tire “creep” is measured by marking the tire & shell, allow the kiln to rotate several revolutions, measure

the distance between the marks, divide the distance by the number of revolutions and that is the “creep”. Creep should be measured weekly and if it approaches or exceeds 1” (25mm), plans should be made to repair or replace the support pads (or on kilns without pads, the shell under the tire would need to be replaced).

To prevent premature and/or uneven wear of kiln tires and support rollers as well as the ability for the kiln to be floated freely within desired positions (no excessive thrust), it is important to have a Hot Kiln Alignment performed at least every other year. Kiln service companies have unique tools and data gathering and analysis equipment to check kilns’ existing centrelines (of tires and rollers) and then make calculated moves to put the centrelines on parallel slope with each other. It is important to note that if only a report is issued that, either the service company or qualified mill maintenance personnel make the corrective moves and any final additional observations and measurements to assure that the kiln is positioned correctly. Part of a good Hot Kiln Alignment will include ovality checks at each pier as this data is beneficial in the alignment analysis but will also provide that data for mill records to determine if shimming or replacement of support pads (in some cases shell section) is needed to prevent refractory problems as described above.



If at any time a kiln is thrusting hard up or downhill or there are bearing issues, it may be necessary to make support roller moves to adjust the kiln position and thrust. The two diagrams below present the “Rule of Thumbs” which will assist mechanics in determining which roller housing to move in which direction. The difference is based on which side of the kiln you are standing on; with the kiln rolling down toward you (palms down) or if the kiln is rolling up away from you (palms up).



It is very critical that a Master Logbook is kept to record any and ALL moves made to the kiln rollers. The Logbook should be maintained in a central location where any mechanics that may make kiln moves have access and use it to record any activities. This will allow trained mechanics to determine where moves have been previously made allowing them to decide where any additional moves should be made or previous moves reversed. It would benefit the maintenance staff if the most recent copy of the Hot Kiln Alignment Report be kept with the Master Logbook as a reference as well as the “Rule of Thumb” diagrams. Any moves made to a kiln should be to relieve thrust of the overall kiln or at a given roller.

REFERENCES

“Lime Reburning: The Rotary Lime Kiln”, by Venki Venkatesh, in Chemical Recovery in the Alkaline Pulp Processing, R. P. Green and G. Hough editors, TAPPI Press, Atlanta, GA, 1992.

“Lime Reburning”, by Terry N. Adams, in Pulp and Paper Manufacture, vol. 5, Alkaline Pulping, T. M. Grace and E. W. Malcolm, technical editors, M. J. Kocurek, editor, Montreal, 1989.

Gorog, J.P. and Fraser, D.G., (1992). “Selection of High Alumina Bricks for Use in Lime Sludge Kilns”, Proceedings of the TAPPI International Chemical Recovery Conference, Volume 2, Seattle, WA, pp. 441-450, June 7-11.