Design of refractory linings for balanced energy efficiency, uptime, and capacity in lime kilns

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ABSTRACT: In this work a computer model is used to examine how refractory linings with both high alumina and basic refractory bricks affect kiln operations. Recommendations are made based on the results to aid mill personnel in designing optimized refractory linings for specific situations.

Kilns used to regenerate lime in the kraft process are highly energy intensive. Throughout the 1990s, in response to increasing fuel prices, the pulp and paper industry primarily used backup insulation in conjunction with high alumina brick to line calcining zones of their kilns. The dramatic decline in price of natural gas over the past decade, in combination with mounting pressures to increase production of existing assets, has led many mills to focus more on increasing uptime and capacity rather than on energy savings. To this end, a growing number of mills are using basic (magnesia based) brick instead of high alumina brick to line calcining zones.

While the use of basic brick can increase the uptime and reduce the cost to maintain the refractory lining, it can dramatically increase the shell temperatures and heat losses. Tradeoffs, therefore, are created among energy efficiency, capacity, and uptime.

Application: Mills can use this information when selecting refractory bricks to optimize life of the refractory lining and increase kiln utilization factors.

Typically, a rotary kiln is used in the kraft process to convert calcium carbonate mud into lime to generate white liquor [1]. Lime mud from a drum or disk filter is fed into the upper feed end of the kiln. Rotation causes the mud to travel down the length of the kiln, where it is exposed to and heated by hot gases traveling in the opposite direction; these hot gases are generated by a burner located at the lower discharge end of the kiln. Production of lime is highly energy intensive; energy consumption ranges between 6.9 and 9.9 GJ/ton (between 6.0 and 8.5 MMBtu/ton) of calcium oxide (CaO) [2]. Despite efforts by the industry to improve energy efficiency, the kiln remains the largest consumer of purchased fossil fuels and carbon emissions in a mill.

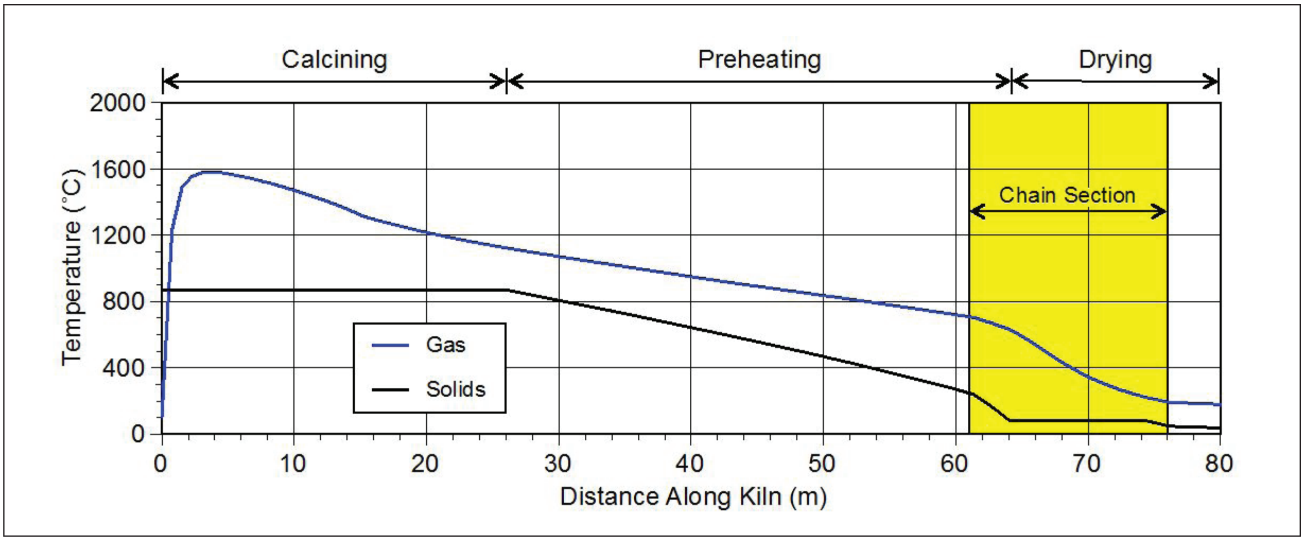
A kiln cannot be operated without the use of a refractory lining to insulate the metal shell from the high temperatures required for calcination. The most important physical characteristic of the refractory lining is its ability to withstand high temperatures and direct chemical attack by the sodium 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 the kiln can be operated with the highest energy efficiency.

Various layouts can be used to construct the refractory lining of a kiln [3]. Traditionally, the refractory linings in North America were built using a single layer of bricks. Kilns in Scandinavia employed a two-layer lining in which high-temperature corrosion-resistant refractory bricks are installed over a layer of insulating bricks next to the kiln shell. Throughout the 1980s and 1990s, due to increasing fuel prices, mills became focused on improving energy efficiency. During this time, many mills in North America started to use the same two-layer refractory linings used by the Scandinavians as a means to save energy.

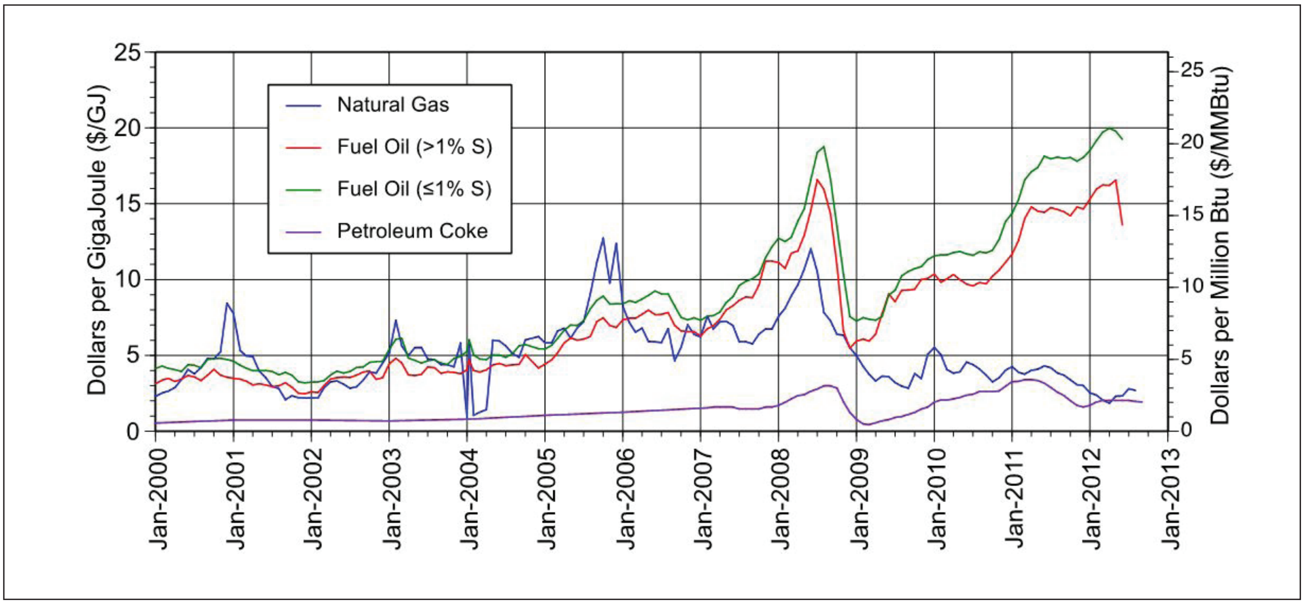
The kiln has three major zones. In the drying zone, mud is dried at nearly constant solids temperatures of around 82°C (180°F). In the preheating zone, the dry material is heated from 80°C to 871°C (175°F to 1600°F) and nodulizing of the dry mud powder occurs. In the calcining zone calcium carbonate ($CaCO_3$) thermally decomposes or calcines to form CaO and carbon dioxide at fairly constant temperatures (around 871°C or 1600°F) of the solids.

Length and relative position of each kiln zone is a function of several factors, such as kiln dimensions, cooler type, burner design, and fuel properties. The temperature profiles for the gas and solids for a kiln with a 3.2-m inside diameter (ID) (10.5 ft) that is 80 m (265 ft) long are shown in **Fig. 1** with the three zones marked.

Fuel oil, natural gas, and pet coke are the main fuels used to fire kilns in the United States. As seen in **Fig. 2**, the prices



1. Predicted gas and solids temperature profiles showing the major zones in the kiln.

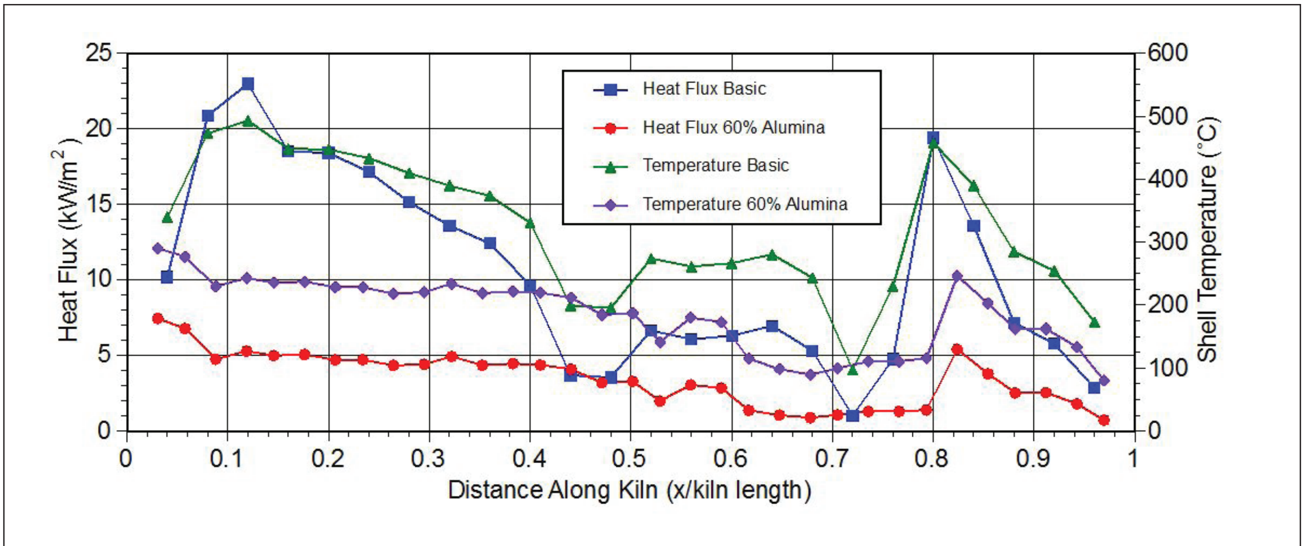


2. Historical U.S. prices for fuel oil and natural gas used to fire kilns in kraft pulp mills.

of oil and natural gas historically have moved together [4-6]. Near the end of 2008, following a long period of rising prices, the prices for both fuels declined sharply due to a drop in demand caused by the recession in the global economy. Moving forward, the expansion of gas production resulting from the application of improved production technologies has kept prices in the United States for natural gas low compared to those for oil. As a result, there is currently a large price gap between oil and natural gas. In 2012, the price for natural gas dropped below that for pet coke. Because of the low prices, the U.S. pulp and paper industry has concentrated on converting kilns that were firing oil and pet coke to natural gas. As a result, only a handful of mills are still firing oil or pet coke in their kilns.

In addition to dealing with changes in the energy markets, to remain competitive many mills have increased the capacity of existing kilns along with other major equipment as a way to reduce manufacturing costs and improve profitability [7]. As a result, it is not uncommon to see kilns running 20% or more above their installed nominal capacity ratings, causing the kiln to become the bottleneck in pulp production.

The low prices for natural gas, coupled with the increased demand for lime, have shifted the focus in kilns away from energy efficiency to process reliability. The pressures to operate the kiln at maximum capacity by avoiding upsets, small stops, and unplanned maintenance are at an unprecedented level, making lost production and cost of repairs due to premature failures of the refractory lining unacceptable in this environment.



3. Increase in shell temperatures and heat losses for a single-layer lining of uninsulated basic bricks versus those for two-layer lining of insulated high alumina bricks.

Given this situation, to increase production and improve reliability, a growing number of mills have started to use basic (magnesia based) bricks instead of high alumina bricks to line the calcining zone of their kilns. Basic bricks do not react with mud to form liquids at the temperatures in the kiln. Furthermore, to shorten the downtime for installation, some mills are installing these bricks without a backup lining. **Figure 3** compares the shell temperature profiles for a kiln in which the calcining zone is lined with two layers of insulated high alumina brick to that for a kiln lined with a single layer of uninsulated basic brick. The shell temperatures of the kiln lined with basic brick are nearly double those for the kiln lined with insulated high alumina brick. The shell heat losses for both kilns are also shown in Fig. 3. Because 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. In addition to higher fuel costs, operating with high shell temperatures may damage the shell.

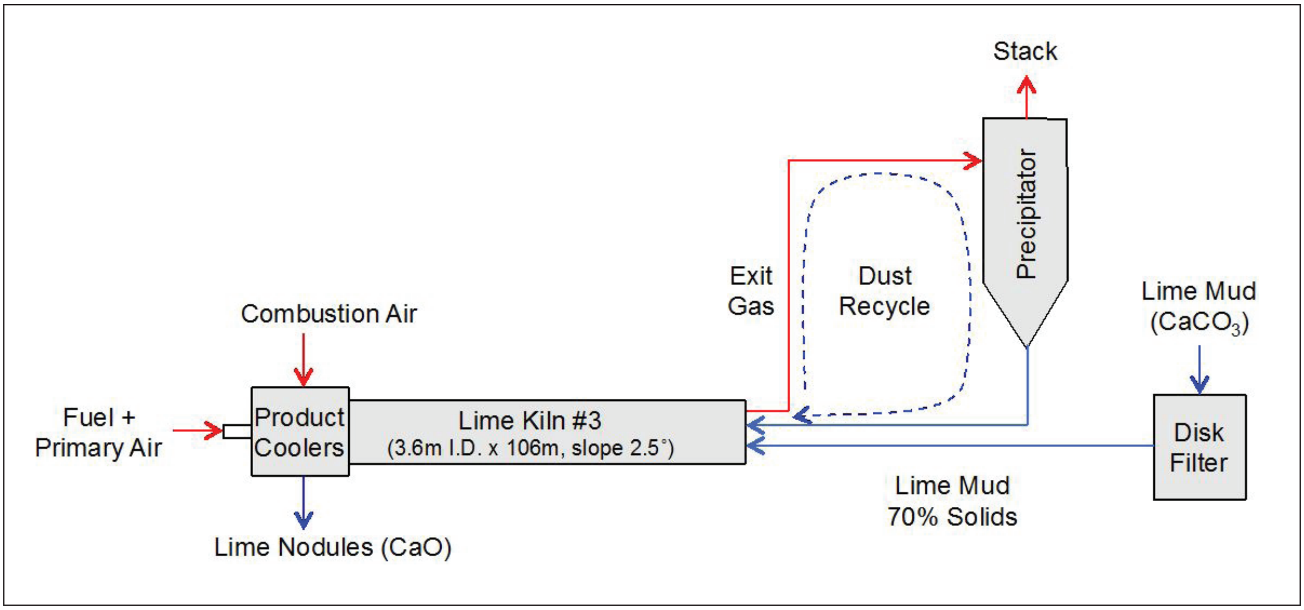
Clearly, there are tradeoffs between energy efficiency, capacity, and uptime. When fuel prices are high, it makes sense to insulate the lining. When fuel prices are lower, trading some thermal efficiency for increased capacity and improved reliability seems reasonable. This paper uses a simple computer model to evaluate a number of refractory linings to identify options to balance these factors.

REFRACTORY MATERIALS FOR LIME KILNS

Calcining zone

High alumina (60% and 70%) and basic bricks are used to line the calcining zone of the kiln. For high alumina bricks, it has been reported [8] that starting around 1450°C (2642°F), the 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 whose behavior is dependent on the raw materials from which the bricks are manufactured. Calcined bauxitic ores consisting mainly of corundum (α-Al_2O_3) are generally used to produce 70% alumina bricks. The 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 ($\alpha Al_2O_3 \bullet 2SiO_2$). 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 and forming a protective layer that retards the reaction of alkali compounds in the mud with the brick. While results from testing show that 60% alumina bricks are substantially more resistant to chemical attack than 70% alumina bricks, both are routinely used in the calcining zone. In all cases, continuous operation above 1500°C (2732°F) can result in premature failure of the refractory lining made using high alumina bricks.

Basic bricks do not react with mud at the temperatures in the calcining zone [9]. As previously mentioned, basic bricks have higher thermal conductivities along with higher densities than high alumina bricks have. Therefore, along with higher shell temperatures, increased weight of a lining made from basic bricks may cause issues with mechanical overloading of the kiln. For these reasons, basic bricks to date have not found widespread acceptance in the pulp and paper industry, although they offer superior resistance to chemical attack.



4. Schematic of kiln #3 used to evaluate the effects of the refractory lining on performance.

Preheating zone

Fire clay bricks are used to line the preheating zone of the kiln. These bricks range from approximately 18% to 44% alumina and from approximately 50% to 80% silica, providing adequate resistance to chemical attack at the operating temperatures in this region and good resistance to cracking or spalling when subjected to rapid changes of temperature. The thermal conductivities of fire clay bricks are less than those for high alumina bricks, which makes them an especially good choice for single component linings.

Drying zone

Because of severe abrasion from the chains sliding down the side of the kiln, high-strength wear-resistant low-cement castable refractory materials reinforced with metal fibers are commonly used to line the drying zone. Various anchoring systems are used to keep the castable lining in place, with some mills recently starting to use insulated metal liners [10]. Depending on the arrangement of the hangers, the use of metal liners can reduce the overall cost and time needed to maintain the chain section. In some cases, when the temperatures are below 250°C (482°F), the shell is left bare.

Backup linings

A variety of insulating bricks can be used in the backup lining. In addition to having low thermal conductivities, these materials must be strong enough at the operating temperatures to stabilize the working lining. Historically, the industry has used insulating brick manufactured using mixtures of diatoms and plastic clays. Care must be taken not to overheat the backup lining when using this type of insulating bricks because their maximum working temperature is around 1000°C (1832°F). Above this temperature sintering occurs, accompanied by severe shrinkage that leads to instability in the lining and possibly brick fallout. Recently, mills have started using low alumina fire clay bricks to construct the backup lining. While offering less insulation, these bricks offer high strength and can withstand much higher temperatures.

KILN STUDY

Equipment layout for kiln

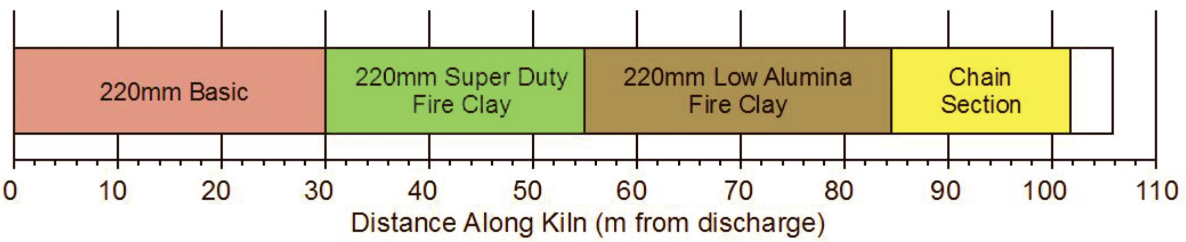
The schematic in **Fig. 4** shows the equipment layout for the kiln used in this study [11]. The kiln has a 3.6m (11.8 ft) ID and is 106 m (348 ft) long with a nominal capacity rating of 270 tons/day. The first 35 m (115 ft) of this kiln are lined with basic brick. The current production rate is 290 tons/day. The kiln is equipped with 10 satellite coolers, a disk filter that supplies mud to the kiln, and an electrostatic precipitator for dust removal. The recovered dust is returned to the kiln feed via a dry handling system.

The layout of the current refractory lining is summarized in **Table I**. To simplify the calculations, the thermal effects of the refractory materials used to construct the dam are ignored while the impact of the discharge dam on the flow of solids in the kiln is taken into account. The error introduced around these assumptions is small.

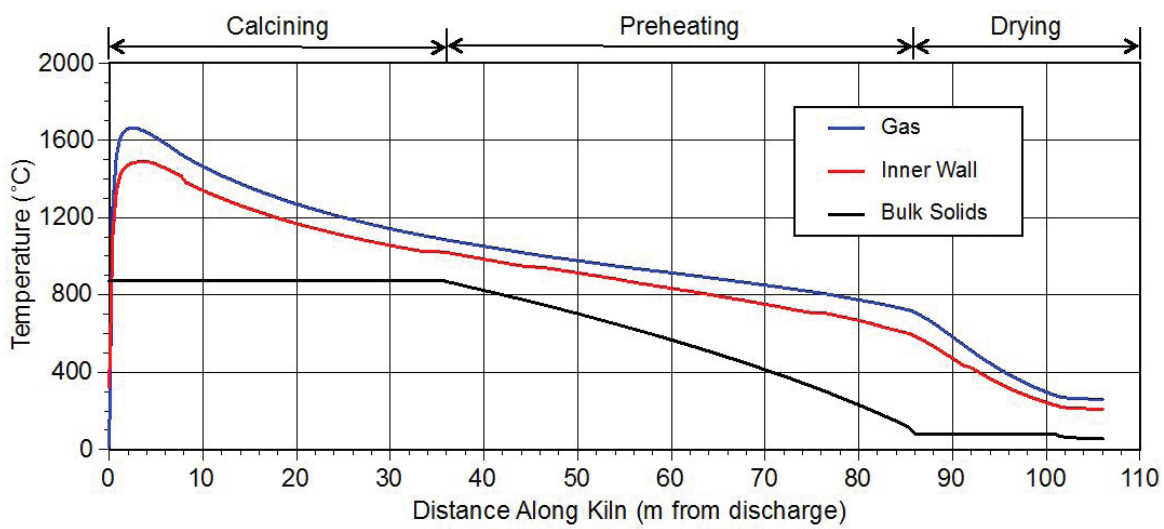
In this work, a computer model was used to predict the temperature profiles of the gas, solids, and shell along with the mass and energy balances for a number of candidate refractory linings. This model has been validated [12,13] in the literature.

Figure 5 shows the predicted temperature profiles for the current operating conditions with the various zones marked on the graph. Because using basic brick results in losing nearly 20% of the total energy input through the shell, additional fuel must be fired to compensate for these

Start (m)	End (m)	Working Lining	Thickness (mm)	Backup Lining	Thickness (mm)
0	35	Basic	220	None	-
35	55	Super duty fire clay	220	None	-
55	85	Low alumina fire clay	220	None	-
85	102	Castable and metal plate		Fiber blanket	
102	106	None	-	None	-



I. Layout of current refractory lining.



5. Predicted temperature profiles for current kiln operating conditions.

losses. As a result, the volume and temperature of the flue gas are increased with more than 15% of the total heat input being lost with the gas leaving the kiln. The predicted and measured flow rates for natural gas are 41.4 m^3/min and 42.7 m^3/min, respectively. The predicted and measured exit gas temperatures are 245°C and 248°C (473°F and 478°F), respectively. On the basis of these results, the computer model does an excellent job predicting the firing rate, flue gas temperatures, and shell temperatures.

Table II lists the types of bricks used in kilns operated in the pulp and paper industry along with their densities, ρ, and the average thermal conductivities, k_{av}.

Layouts of refractory linings

Table III shows the layouts of the various refractory materials for each lining. All the linings are taken from operating kilns. The calcining zones in layouts A1–A4 are lined with 60% alumina bricks. The calcining zones in layouts

Classification	Zone	ρ (g/cm³)
Basic	Calcining	2.8
60% Al_2O_3	Calcining	2.6
Super duty	Preheating	2.2
High duty	Preheating	2.1
Low alumina fire clay	Preheating + Backup	1.6
Insulating	Backup	0.9
Low cement castable	Drying	2.3

II. Refractory bricks used to line kilns in the pulp and paper industry.

M1–M4 are a combination of basic and 60% alumina bricks. In all cases, the chain section is lined using 102 mm (about 4 in.) of low cement castable. Also, the amount of chain hung in the kiln is maintained at its current level. The layouts used in the study were selected to cover the full range of linings currently used in the industry.

RESULTS OF MODEL SIMULATIONS

Table IV shows the key operating variables for each refractory lining. Not surprisingly, two-layer linings show better thermal performance, with the fuel consumption and exit gas temperatures showing improvement. That is, the effect of the increased insulating value of two-layer linings is to

Lining		Distance Along Kiln (m)					
		0–15	15–30	30–55	55–85	85–102	102–106
A4	Hot Face	205 mm 60% Alumina	205 mm 60% Alumina	115 mm Super Duty	155 mm High Duty	102 mm Castable	No Lining
	Backup	50 mm Insulating	50 mm Insulating	65 mm Insulating	65 mm Insulating		
A3	Hot Face	205 mm 60% Alumina	205 mm 60% Alumina	115 mm Super Duty	220 mm Low Alumina	102 mm Castable	No Lining
	Backup	50 mm Low Alumina	50 mm Low Alumina	65 mm Low Alumina	No Backup Lining		
A2	Hot Face	205 mm 60% Alumina	205 mm 60% Alumina	115 mm Super Duty	155 mm High Duty	102 mm Castable	No Lining
	Backup	50 mm Low Alumina	50 mm Low Alumina	65 mm Low Alumina	65mm Low Alumina		
A1	Hot Face	220 mm 60% Alumina	220 mm 60% Alumina	220 mm Super Duty	220 mm High Duty	102 mm Castable	No Lining
	Backup	No Backup Lining					
M4	Hot Face	200 mm Basic	205 mm 60% Alumina	115 mm Super Duty	155 mm High Duty	102 mm Castable	No Lining
	Backup	50 mm Insulating	50 mm Insulating	65 mm Insulating	65 mm Insulating		
M3	Hot Face	200 mm Basic	205 mm 60% Alumina	115 mm Super Duty	220 mm Low Alumina	102 mm Castable	No Lining
	Backup	50 mm Low Alumina	50 mm Low Alumina	65 mm Low Alumina	No Backup Lining		
M2	Hot Face	200 mm Basic	205 mm 60% Alumina	115 mm Super Duty	155 mm High Duty	102 mm Castable	No Lining
	Backup	50 mm Low Alumina	50 mm Low Alumina	65 mm Low Alumina	65 mm Low Alumina		
	Hot Face	220 mm Basic	220 mm Basic	220 mm Super Duty	220 mm High Duty	102 mm Castable	No Lining
	Backup	No Backup Lining					

III. Layouts of the refractory linings.

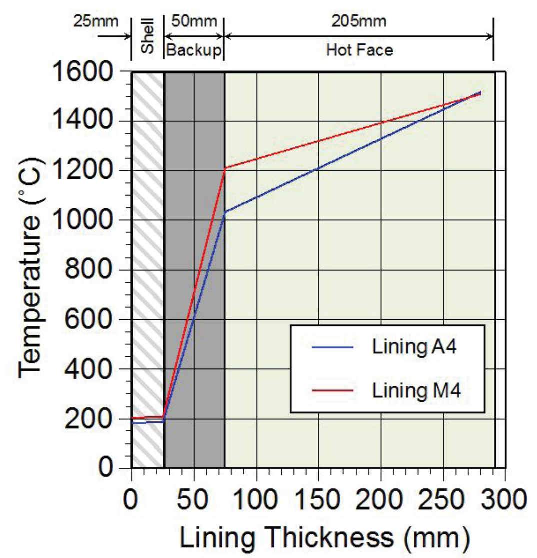
Lining	Fuel Consumption (GJ/ton)	Exit Gas Temperature (°C)	Shell Heat Loss (GJ/h)	Fuel Flow (GJ/h)	Peak Wall Temperature (°C)	Peak Shell Temperature (°C)
A1	8.43	196	19.02	89.99	1502	302
A2	7.89	180	15.73	84.20	1511	247
A3	7.82	182	15.02	83.53	1510	246
A4	7.30	168	11.05	77.87	1517	183
M1	9.56	243	23.35	101.95	1480	397
M2	8.10	189	16.85	86.45	1502	293
M3	8.04	192	16.14	85.79	1502	293
M4	7.34	170	11.51	78.54	1514	205

IV. Impact of refractory lining on key operating variables.

reduce both the shell heat loss and back-end energy loss. For a single layer of alumina brick, configuration A1, 19% of the energy input with the fuel is lost through the shell. The amount of energy lost through the shell for the single layer of basic brick is 23%. For alumina and basic bricks, the addition of low alumina fire clay brick as a backup lining drops the shell heat losses to around 16% of the total energy input of the fuel. The use of an insulating refractory material as backup lining drops the shell heat losses to just over 11% of the total energy input of the fuel. In all cases, peak wall temperature increases with the insulating value of the lining.

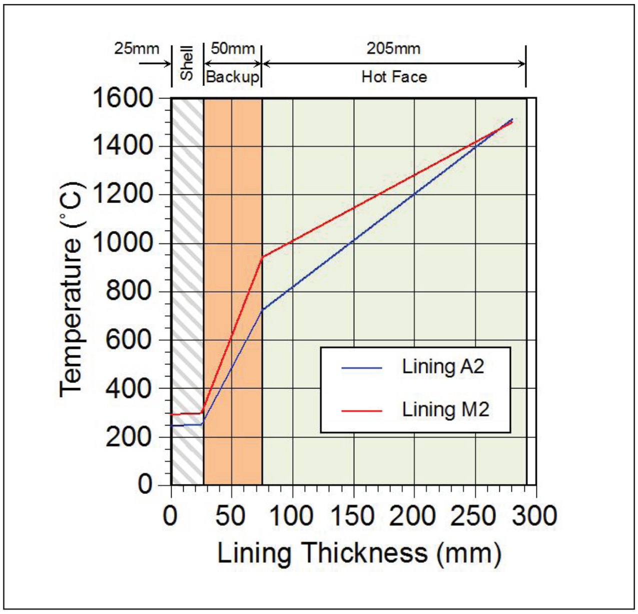
For alumina brick, moving from a single-layer to a two-layer lining using an insulating brick increases the inner wall temperature from 1502°C to 1517°C (2736°F to 2763°F). While this is not a large increase, it can be very significant. As previously described, starting around 1450°C (2642°F) sodium compounds and other impurities in the mud begin to react with alumina and silica in the bricks to form liquids. While single-layer linings have lower wall temperatures and are, therefore, more forgiving, the operators must be extremely careful to control the level of residual carbonate in all cases using high alumina bricks. Overfiring the kiln for even short periods can severely damage the refractory linings. When using basic brick, the inner wall temperature is not an issue because under normal operating conditions the mud will not react with basic bricks.

Table IV also shows that the peak shell temperature for a lining made using a single layer of basic brick approaches 400°C (750°F). For a single-layer lining of alumina brick, the peak shell temperature drops to 300°C (572°F). For both alumina and basic brick, insulating the lining reduces the shell temperatures well below 200°C (392°F). The shell for kiln #3 is made with structural rolled steel plate ASTM A36, which is typical for the industry. The tensile strength of this type of steel at room temperature is 400-550 MPa (58000-80000 psi) with the strength declining to 310 MPa (45000 psi) at 400°C (750°F) [14], a decrease of more than 20%. Therefore, operating at temperatures above 400°C (750°F) for extended periods may lead to permanent deformation of the shell, requiring shell replacement, or shell failure unexpectedly forcing an extended shutdown for repair.

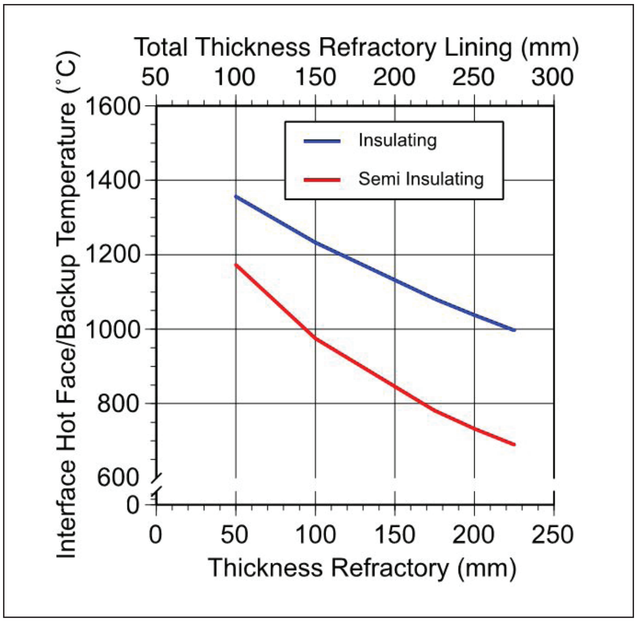


6. Predicted temperature profile through the wall using two-layer lining of 60% alumina or basic brick along with insulating brick, lining A4 and M4.

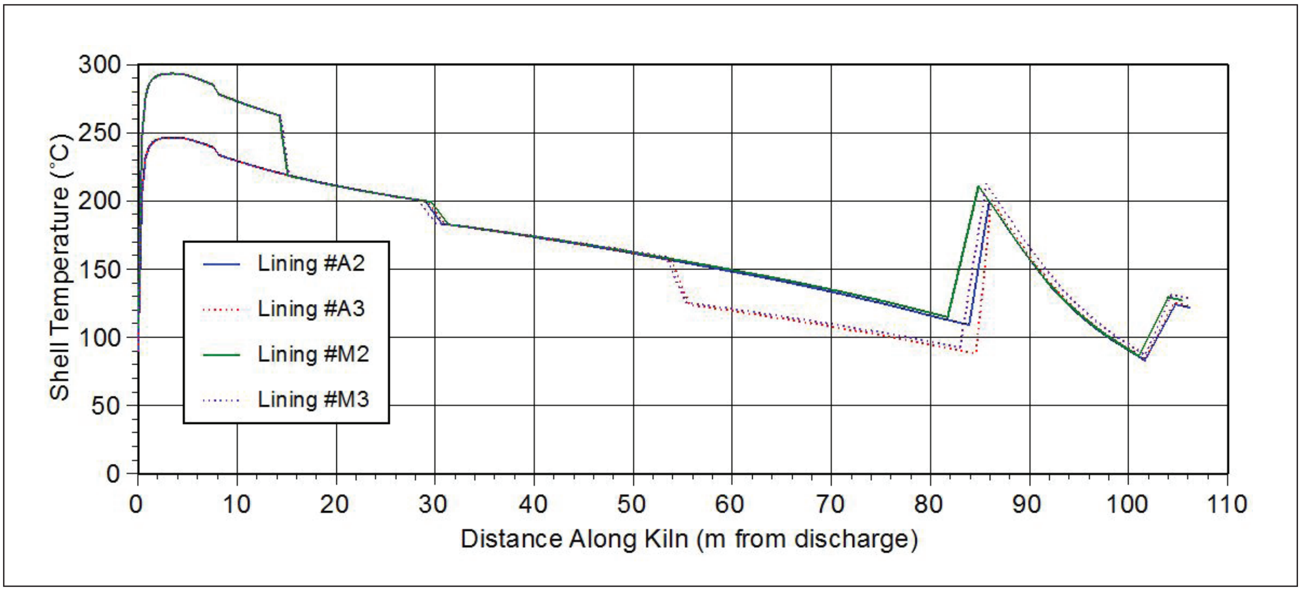
Figure 6 shows that the temperature of the insulating brick used with alumina brick, lining A4, exceeds 1000°C (1832°F), the maximum recommended operating temperature for the insulating brick. Figure 6 also shows that the temperatures of the insulating brick used with basic brick, lining M4, also exceeds the maximum operating temperature for the insulating brick. The temperatures of the linings made using low alumina fire clay bricks with alumina



7. Predicted temperature profile through the wall using two-layer lining of 60% alumina or basic brick along with low alumina fire clay brick, linings A2 and M2.



8. Interface temperature of hot face and backup lining for two-layer system using 60% alumina brick over insulating and low alumina fire clay brick, linings A2 and A4.

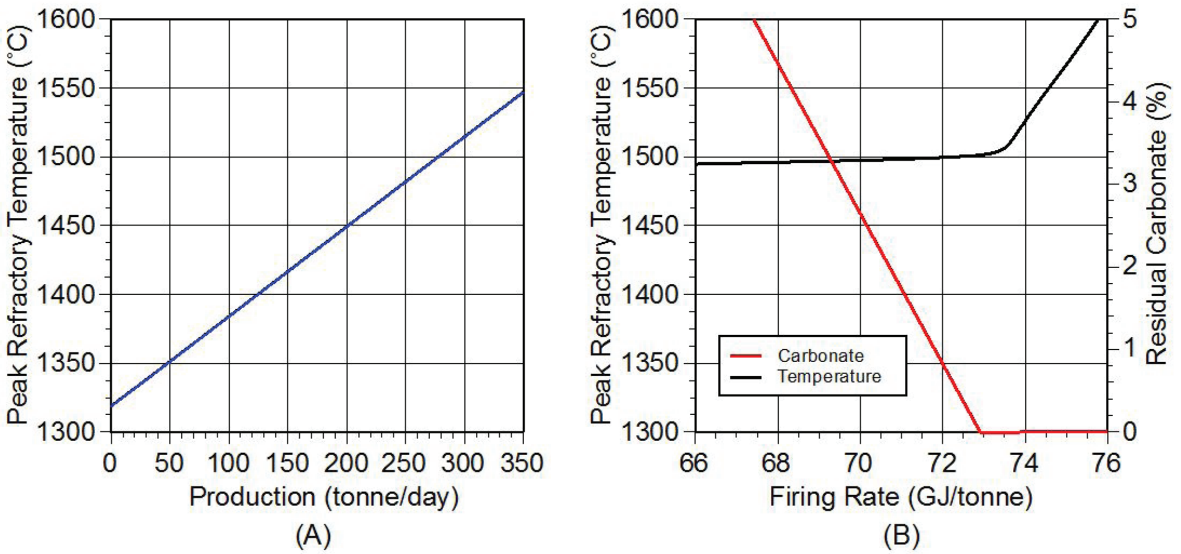


9. Comparison of predicted shell temperatures for combination of two-layer basic and alumina bricks in the calcining zone with dual- and single-layer lining of low alumina fire clay brick in the preheating zone, linings A2, A3, M2, and M3.

or basic brick, linings A2 and M2 (**Fig. 7**), are well below the recommended maximum operating temperature of 1372°C (2500°F) for this material.

Figure 8 shows how thinning of the hot face high alumina brick affects the temperature for the backup linings using both insulating and low alumina bricks, linings A4 and A2. Thinning of the alumina brick or loss of any coating on the inner wall will quickly increase the temperatures for the insulating brick, lining A4, to unacceptable levels. For low alumina brick, lining A2, the thickness of the hot face brick can decline to 100 mm (4 in.) before the lining needs to be replaced.

Figure 9 compares shell temperature profiles for a traditional two-layer lining using 60% alumina bricks in the calcining zone and fire clay bricks in the preheating zone over a backup lining of low alumina fire clay bricks, lining A2, to those in which a portion of the preheat zone is lined with a single layer of low alumina fire clay bricks, lining A3. Figure 9 also shows the same shell temperature profiles using a combination of basic and alumina brick in the cal-



10. Effects of kiln production (a) and firing rate (b) on peak refractory temperatures. Above 1500°C (2732°F) mud begins to react with the refractory to form liquids that penetrate into the brick, causing rapid failure of the lining.

cining zone, linings M2 and M3. In all cases, for current operating conditions, shell temperatures in the preheating zone using the low alumina fire clay bricks are lower than temperatures for the two-layer lining. In addition, the use of a single layer of semi-insulating brick in the preheat zone simplifies installation of the lining.

RESULTS AND DISCUSSION

In the case of kiln #3, **Fig. 10a** shows how increasing the production rate increases peak temperatures when alumina brick with backup lining of insulating brick is used in the calcining zone of the kiln. **Figure 10b** shows that increasing the firing rate, for a given production rate, also increases peak temperatures of the refractory lining. The increase in temperature is more pronounced once all carbonate has been completely calcined (i.e., the level of residual carbonate is zero). Unfortunately, for the geometry and operating conditions of kiln #3, the calculations suggest a conventional insulated two-layer alumina lining will not work because the refractory temperatures are very close to maximum allowable values. The model results are validated by the operating experience of the mill. The calcining zone was originally lined with a two-layer lining of 60% alumina brick (205-mm 60% alumina brick over 50-mm insulating brick). Because of repeated failures of the refractory lining from localized overheating and overloading of the insulating lining, the two-layer system of 60% alumina bricks was gradually replaced with a single layer of basic bricks.

Table V shows energy consumption for all of the refractory linings included in this work. The linings are listed in order of increasing energy consumption with the traditional two-layer system, lining A4, offering the lowest energy consumption. The first 30 m of kiln #3 are lined with a single layer of basic brick, lining M1. The energy consumption for this lining is 30% higher than energy consumption for an insulated lining using high alumina brick.

Lining Number	Heat Rate (GJ/h)	Annual Oil Consumption (kBOE/year)	Annual Natural Gas Consumption (Mcm/year)	Energy Multiplier
A4	77.87	104.90	16.32	1.00
M4	82.19	110.72	17.22	1.06
A3	83.53	112.52	17.50	1.07
A2	84.20	113.42	17.64	1.08
M3	85.79	115.57	17.98	1.10
M2	86.45	116.46	18.12	1.11
A1	89.99	121.23	18.86	1.16
M1	101.95	137.34	21.36	1.31

V. Impact of kiln lining on the energy consumption for kiln #3.

In looking at the various options, lining M4 appears to be a reasonable option for kiln #3. This lining uses a very short section of basic brick in the hottest region of the calcining zone. To avoid overheating the backup lining, low alumina fire clay bricks are used to insulate the basic brick. High alumina brick is used in the remainder of the calcining zone. The preheating zone is lined with super duty brick insulated with low alumina fire clay brick, followed by a section lined with a single layer of low alumina fire clay brick. The energy consumption for this lining layout is only 6% higher than energy consumption of the conventional lining using high alumina brick. Using insulating brick behind the high alumina brick in the calcining zone and extending the use of low alumina fire clay brick in the preheating zone of the kiln could achieve further reduction in energy consumption.

CONCLUSIONS

Generally, mills have done well using insulated high alumina bricks to line the calcining zone of the kiln. Yet, for kilns running at high production rates or low targets for residual carbonates, this lining may not work. For these kilns, basic refractory bricks should be considered for the calcining zone insulated using low alumina fire clay bricks to avoid overheating of the steel shell. The use of this approach should eliminate emergency shutdowns due to localized overheating of the refractory lining. Damage from these types of failures can result in high costs and risks, such as permanent damage from localized overheating that causes distortion of the kiln shell and makes it difficult to rebrick. Also, the misalignment in the shell caused by such deformations may induce frequent lining failures.

Refractories ordered in emergency situations may not be the most suitable for the application, and the delivered price is usually higher than programmed orders. After a few unscheduled shutdowns, the kiln will be lined with many different products that may in turn wear at different rates, causing other unexpected shutdowns. In addition, every time the kiln is stopped for emergency repairs the rest of the lining is subjected to additional thermal and mechanical stresses. Emergency shutdowns do not allow maintenance crews to work on other parts of the kiln that would potentially shorten scheduled maintenance and thereby offset some the unscheduled downtime.

ABOUT THE AUTHORS

In response to increased demands for lime and lower energy prices, a growing number of mills have starting using basic (Mag-Spinel) brick to line the burning zones of their kilns to improve the service life of the refractory lining. Whereas the primary focus of previous work was on the use of high alumina brick, we included basic and insulating bricks for use in the burning zone.

A considerable amount of time was spent gathering data from an operating kiln to validate the results of the work. It is very important for mills to keep accurate records of the type and performance of the brick installed in their kilns. Without this information, it becomes very difficult to optimize the performance of the refractory lining.

The work clearly showed the tradeoff between energy savings and service life of the refractory lining. The amount of insulation in the burning zone must be kept at a minimum to avoid overheating the working lining. Because of historically high prices for fuel, mills have a tendency to install too much insulation.

Mills can use this information when selecting refractory bricks to optimize the life of the refractory lining, leading to an increased kiln utilization factor. The use of basic brick can increase the service life of the refractory lining.

Basic bricks have higher thermal conductivities and weigh more than high alumina bricks. The industry will benefit from a new family of refractory bricks to be developed. These bricks would offer increased resistance to chemical attack without the dramatic increase in thermal conductivity and weight associated with traditional basic bricks.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Clearly, the avoidance of these issues justifies a small increase in energy consumption. To minimize the impact on fuel consumption, basic brick should only be used in the hottest region of the calcining zone. Usually, the use of basic bricks is limited to a section of kiln equivalent to no more than 5 diameters just uphill from the discharge dam. **TJ**

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