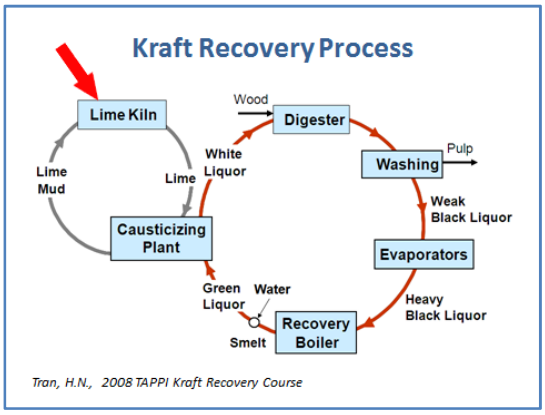
LIME KILN COMBUSTION, HEAT TRANSFER AND OPTIMIZATION

Richard Manning
Former Director & Chief Technology Officer, KFS

INTRODUCTION

The location of the lime kiln on the Kraft recovery process is shown below.



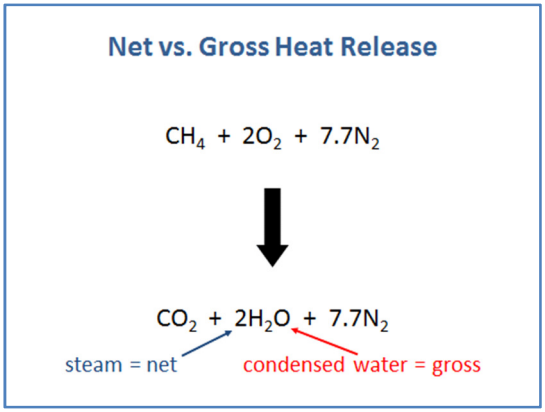
COMBUSTION AND HEAT TRANSFER

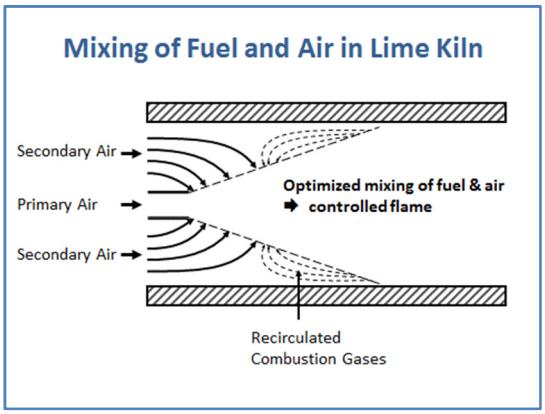
The combustion process involves conversion of fuel to oxidized components releasing energy primarily in the form of heat and light. For traditional fuels used in the kraft recovery process, the core components of the fuel are carbon and hydrogen in the form of hydrocarbons. Using the simplest form of hydrocarbon, methane, the basic combustion process is:

$CH_4 + 2\ O_2 + 7.7\ N_2$ ➔ $CO_2 + 2\ H_2O + 7.7\ N_2$
fuel air combustion products

The actual heat released in the kiln is the 'net' heat reflecting the conversion of fuel to CO_2 (gas) and water vapor. In the US heat release values are quoted in 'gross' terms reflecting higher energy release to produce CO_2 (gas) and liquid water.

The primary air has high momentum (mass flowrate x velocity) compared to the surrounding secondary air. This difference in momentum causes the primary air to draw into the center the secondary air.

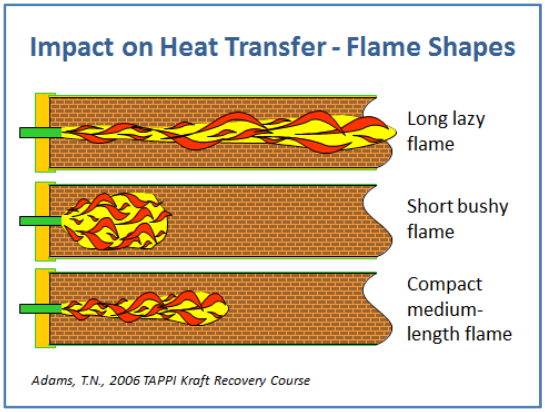




Since the main control of flame profile and combustion is fuel and air mixing, cold flow modeling techniques can be used to visually simulate the combustion process in lime kilns as shown below.

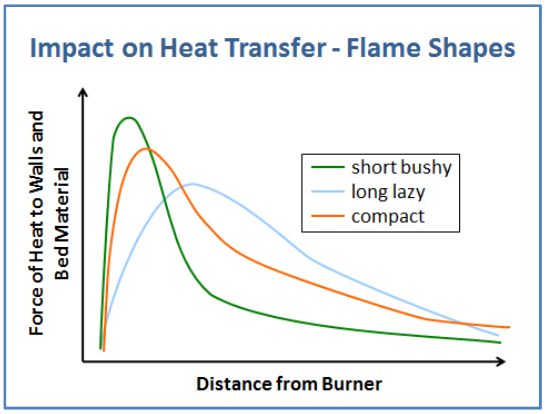


The burner and flame play an important role in product quality and refractory service life. As with all combustion fired heat exchange equipment, higher flame temperatures mean higher production capacity and efficiency. However, excessive temperatures cause refractory damage, and over-burned, slow-reacting lime product. This tradeoff in performance results in a compromise in flame length. Three types of rotary kiln flames are shown below:

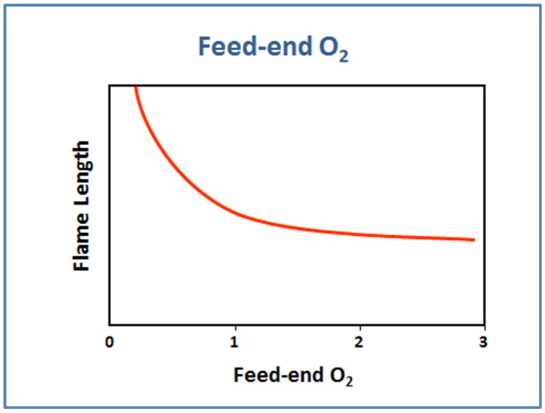


Longer flames are cooler, lazy and less well defined often washing on the kiln refractory and releasing heat well down the kiln. Shorter flames are too hot and cause refractory damage and overburned lime, while longer flames cause some loss in production capacity and efficiency, and loss of control of the product quality. A compact, medium-length flame is a good tradeoff between efficiency and refractory service life. The heat transfer from each type of flame shape is shown below.

It can be seen that the fuel requires oxygen to burn. The balance shown is stoichiometric i.e. exactly the right amount of air is provided to burn with the fuel, no more and no less. In practice, combustion process operation with excess air to ensure that all the fuel is consumed and pollutants such as carbon monoxide are released. However too much excess air results in energy being wasted heating up the spare oxygen and additional nitrogen to combustion temperatures. So minimum excess air is often used, and particularly in lime kilns. Excess air is measured as spare oxygen metered at the feed-end of the kiln and/or at the stack.



Given that fuel has to meet oxygen to burn, as the excess oxygen is reduced there comes a point where the fuel has difficulty mixing with the last spare oxygen because the oxygen becomes a rare commodity. The result is that the combustion process takes longer and travels further before being complete as shown below.



This optimum flame length varies slightly for different kiln configurations; a kiln equipped with a discharge end dam will typically operate more efficiently with a shorter, slightly wider flame. This is due to the deeper and wider bed that is formed behind the dam allowing the heat transfer to occur over a greater area without directly impacting the refractory. The material also has a slight increase in retention time in the kiln allowing the heat to "soak" in more thoroughly. A kiln without a discharge end dam will have a narrower bed and shorter retention time requiring additional kiln length and therefore time for the bed to be fully heated. In general; flame length for a kiln with a discharge end dam is typically 3 to 5 times the kiln diameter in length measured from the discharge end of the kiln, without the dam; 6 to 8 times the kiln diameter. Flame length can be monitored by recording the temperature profile on the kiln shell, a significant drop in temperature will show at the end of the flame.

However, irrespective of the shape, the flame must not touch the refractory, or serious refractory washing will occur.

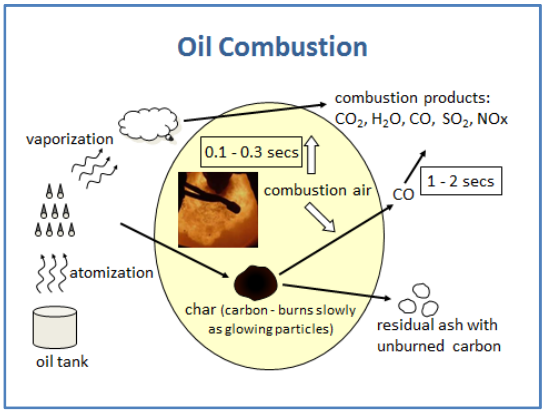
More recently combustion equipment suppliers have developed validated physical and computational means to "model" flame and heat transfer characteristics in a given kiln. This is valuable as it accounts for external effects such as secondary air flow paths that can dramatically affect the flame. Many "modeled" burner designs have been installed and have resulted in increased

operating efficiency, improved product quality, increased capacity and reduced refractory wear.

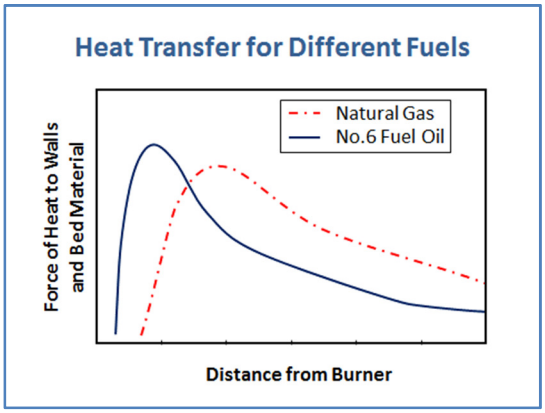
TRADITIONAL FUELS

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 results in higher kiln capacity. Natural gas easier to use and currently cheaper.

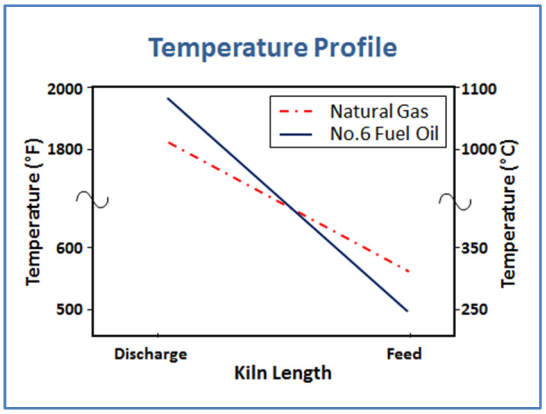
Commercially used liquid fuels range from gas (diesel) oil through to heavy fuel oil. The liquid fuels are atomized to create a spray of tiny droplets (see below). Combustion takes place in the vapor phase around the droplets before finally burned at the surface of the remaining fuel creating a very visible and luminous flame.



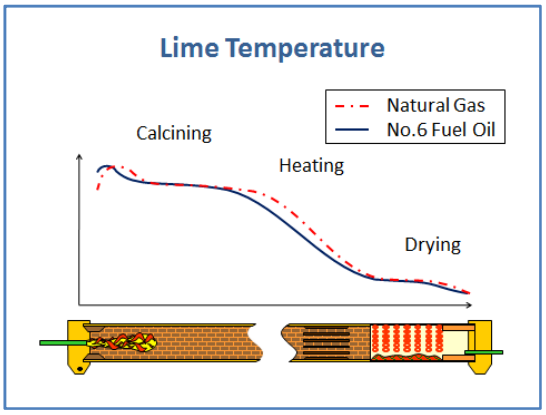
Natural gas burns with signifcantly less luminosity resulting poorer radiation and flatter heat flux profile along the kiln starting further from the kiln discharge as shown below.



The result is different positions for the calcination zone in the kiln which leads to very different temperature profiles in the kiln for the operator between oil and natural gas firing.



The zones for drying, heating and calcination change also which impacts on the kiln dynamics, responsiveness and capacity.



It is important to recognize that achieving 100% oil flame characteristics with natural gas flame is not possible in any combustion system. It is possible to increase the heat transfer from gas flame but this must be considered within the system constraints of each kiln and take into account:

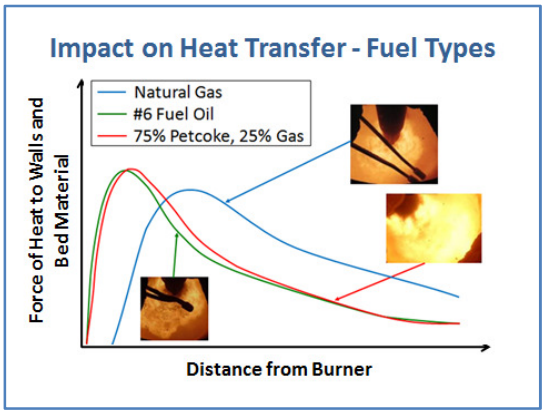
- moderate increase in luminosity
- increase flame temperature
- flame shape and size
- dual fuel firing

The challenge is to bring the heat closer to the front-end of the kiln thereby making the kiln longer and more productive.

There has been in recent years a number of kilns are at least partially fired with petroleum coke (petcoke) when traditional fuels have elevated prices. Petcoke, a by-product from the oil refining process and historically has been a relatively

cheap fuel Petcoke is a difficult fuel to burn due to low volatiles content and hence has to be co-fired with natural gas or oil to support flame stability, typically contributing 60-75% of the total heat load.

Petcoke is an efficient kiln fuel and performs well in the lime kiln as long as the sulfur and vanadium contamination is not too high. The sulfur content of petroleum coke can slightly derate the kiln due to the formation of $CaSO_4$, and the metals require somewhat higher use of purchased lime. These two impacts are offset by the lower cost and better energy efficiency. While petcoke firing often produces much higher NOx in terms of kiln performance it acts more closely to heavy fuel oil. A comparison of heat transfer for natural gas, heavy fuel oil and petcoke/gas co-firing is shown below.



BIO-FUELS

The concept of the bio-refinery and pump mills being self-sufficient in energy is growing pace rapidly. A number of pulp mill derived fuels are already being used or tested.

Solids include wood derived fuels such as wood and bark powder which have been fired directly in kilns as the main kiln fuel. The non-process elements (NPEs) in these fuels are usually low enough so that modest increase in lime makeup can control buildup of NPEs in the recovery loop.

Wood, coal and other fuels have been used for many years to provide clean fuel-gas by gasification. The lower cost of the gasification fuel offsets the high capital cost of the equipment needed to gasify these fuels. Good, stable operation is possible with gasification at on-line availability of around 85%. Performance of gasifier fuels in lime kilns is similar to natural gas in terms of production capacity and Heat Rate. Wet gasifier feedstocks can de-rate the kiln and the both the burner and chain section need to be designed for gasifier fuels.

There are several fuels generated within the pulping and kraft recovery process. Turpentine, methanol, stripper off-gas (SOG), and non-condensable gases (NCG) have all been burned in lime recovery kilns. The energy content of these "fuels" varies considerably, but each makes a contribution to overall heat input. These materials contain some sulfur that can derate the kiln capacity, and all of them lower the heat rate of the kiln.

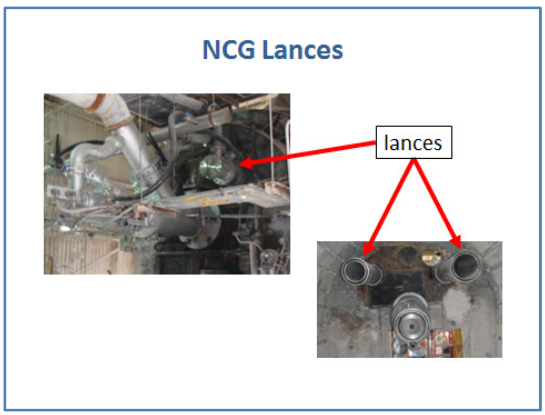
Tall oil has been used to fire lime kilns where its value as a mill product is low. It is a good kiln fuel with relatively low sulfur and good heating value. It would have a Heat Rate similar to fuel oil

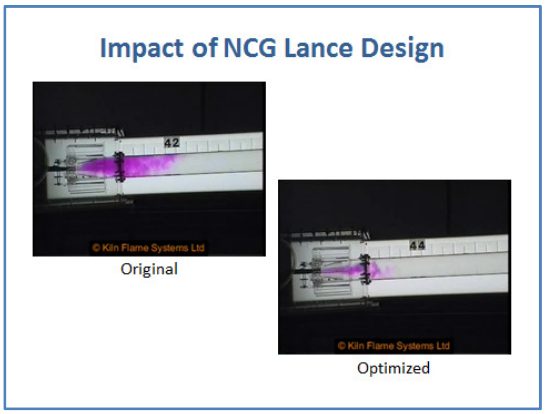
Pyrolysis oils have also been proposed for lime kilns and are being trialed. Some fuel handling problems need to be overcome to make this attractive.

There are several schemes to separate lignin from the black liquor to increase recovery boiler capacity. There a number of commercial options being developed for lignin use but it has also prove. Lignin is difficult to handle due to its low melting point and explosive characteristics, however it has been successfully operated continuously in recently in Finland.

BURNING NCGS

Waste gases (non-condensible gases, stripped off-gases, etc) are often disposed of in the kiln via dedicated separate lances as shown below. These gases can often have serious impact on flame profile, production and product quality if not correctly designed.





KILN CONTROL AND OPTIMIZATION

The purpose of the kiln operation is to manage the inventories i.e. do not let the mud tank empty or overflow, do not let the lime bin empty or completely fill.

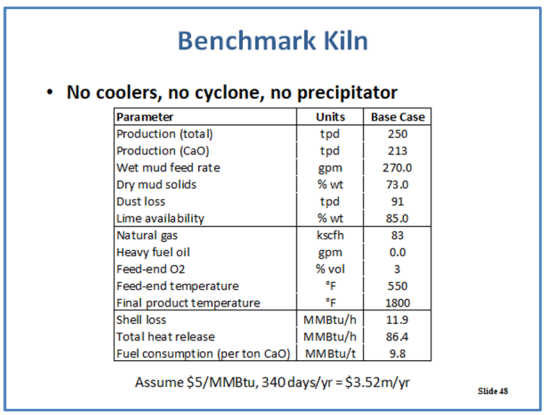
Given the material residence time in the kiln is 2-4 hours, changes to the kiln operation can take some time to manifest themselves. Hence small frequent changes are better than few large changes.

Kiln stability is achieved through:

- stable production: constant mud feed rate & density
- stable heat transfer profile: constant primary air:fuel and feed-end O_2
- stable kiln temperature profile: constant burning zone and feed-end [constant external dryer exit]

Results in constant carbonates 1% > Y > 3%

To evaluate optimization options, a benchmark kilns is taken as a starting point.



From the benchmark, a number of kiln improvements are considered as below:

- addition of product coolers
- improved dry solids from mud filter
- addition of dust cyclone
- lower shell losses from improved insultation
- convert to more luminous fuel e.g. oil
- upgrade chain system (where appropriate)
- better lime quality
- lower kiln exit O_2
- optimization of all above

Parameter	Units	Base Case	Cooler	% Dry Solids	Cyclone	Refractory	Oil
Production (total)	tpd	250	250	250	250	250	250
Production (CaO)	tpd	213	213	213	213	213	213
Wet mud feed rate	gpm	270.0	270.0	270.0	233.5	270.0	270.0
Dry mud solids	% wt	73.0	73.0	78.0	73.0	73.0	73.0
Dust loss	tpd	91	91	91	22	91	91
Lime availability	% wt	85.0	85.0	85.0	85.0	85.0	85.0
Natural gas	kscfh	83	76	79	79	79	0
Heavy fuel oil	gpm	0.0	0.0	0.0	0.0	0.0	9.0
Feed-end O2	% vol	3	3	3	3	3	3
Feed-end temperature	°F	550	542	595	565	550	500
Final product temperature	°F	1800	535	1800	1800	1800	1800
Shell loss	MMBtu/h	11.9	13.1	11.9	11.9	9.2	11.9
Total heat release	MMBtu/h	86.4	79.5	82.1	82.8	83.0	78.7
Fuel consumption (total)	MMBtu/t	8.3	7.6	7.9	8.0	8.0	7.6
Fuel consumption (per ton CaO)	MMBtu/t	9.8	9.0	9.3	9.4	9.4	8.9
	Energy Saving		8.0%	5.0%	4.2%	4.0%	8.9%

Parameter	Units	Base Case	Chain	Lime	O2	Optimized
Production (total)	tpd	250	250	231	250	232
Production (CaO)	tpd	213	213	213	213	213
Wet mud feed rate	gpm	270.0	266.6	259.9	270.0	224.1
Dry mud solids	% wt	73.0	73.0	73.0	73.0	78.0
Dust loss	tpd	91	84	91	91	22
Lime availability	% wt	85.0	85.0	92.0	85.0	92.0
Natural gas	kscfh	83	80	81	80	64
Heavy fuel oil	gpm	0.0	0.0	0.0	0.0	0.0
Feed-end O2	% vol	3	3	3	1.5	1.5
Feed-end temperature	°F	550	500	550	525	600
Final product temperature	°F	1800	1800	1800	1800	535
Shell loss	MMBtu/h	11.9	11.9	11.9	11.9	10.4
Total heat release	MMBtu/h	86.4	83.9	85.0	84.0	66.4
Fuel consumption (total)	MMBtu/t	8.3	8.0	8.8	8.1	6.9
Fuel consumption (per ton CaO)	MMBtu/t	9.8	9.5	9.6	9.5	7.5
	Energy Saving		3.0%	1.7%	2.8%	23.4%

FURTHER READING ON LIME REBURNING KILNS

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

2. “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.