Lime, CaO, is the reagent used in the slaking and causticizing process of the kraft pulping process. In the slaker and causticizer, green liquor containing sodium carbonate is reacted with lime to form sodium hydroxide, a key reagent in the wood cooking process. The CaCO₃ formed in the causticizing process is separated out from the white liquor (sodium hydroxide and sodium sulfide) and is sent to the lime kiln to be converted back to CaO.

The lime kiln is used to convert lime mud, CaCO₃, to lime, CaO. This reaction will take place at temperatures above 1600°F with the liberation of CO₂ from the calcium oxide. So the essence of the kiln process is to dry the lime mud, heat it to calcining temperature, and hold it at or above that temperature long enough for the reaction to go to completion.

The kiln is a rotating tube made of metal and refractory brick. The tube is inclined so the mud enters at the high (feed) end, and the lime exits at the low (front, or hot) end. A burner is provided at the front end to burn oil, natural gas, or other fuels. Thus we have a counter flow of gases and solids, with the combustion gases flowing up from the front end toward the back end while the mud, under the action of gravity and the slow rotation of the tube, flows from the feed end to the front end.

The kiln operator is usually stationed in a control room near the front end of the kiln. In addition to the information she derives from instruments on the process, she may directly inspect the kiln through openings or windows in the front end. If Dante were writing today, he might gain new insights into the character of hell by observing the front end of a lime kiln in action. The kiln operator will also travel to the feed end of the kiln several times a shift to examine and maintain the operation of the mud filter which cleans and dewatered the mud prior to its entry into the kiln. Since the kiln may be as long as a football field, this trip takes the operator away from the control room for a period of time. Sometimes the kiln job is shared by two operators, although in those cases there may be additional processes included in their sphere of activities.

The inside diameter of a 100 ton per day kiln would be about 10 feet. Such a kiln would be adequate for a 500 ton per day kraft mill. Larger mills may use multiple kilns or a single rather larger kiln. While the kiln process is not usually considered hazardous, the operator is responsible for a burner producing a flame that extends 30 feet into a kiln and fills a large part of its 10 foot diameter. The product of the process is a glowing hot solid. The operator must manually interact with the solid to obtain samples for analysis and perhaps to break up large agglomerates (balls) that will interfere with down stream processing. Steel tools with handles 10 feet long are available for such actions.

Gases are removed from the process by entering the suction of the "induced draft fan" located at the back end of the kiln. The front end is frequently open to the air, so the pressures within the kiln are below atmospheric. They are referred to as "draft" rather than pressure for that reason. One hazard that is well recognized is the possibility that if the fan does not maintain the draft at a high enough level, the flame will blow back out the front end of the kiln. Safety devices are used to stop the kiln fuel flow if the draft drops to too low a level.
Figure 1 is the P&I diagram of a lime kiln. This kiln uses two fuel sources, oil and natural gas. Each of these fuels is supplied via a flow controller. Air makes up the main volume of the gas supplied to the kiln but it is usually not measured directly. This diagram does not show it but there are usually two points of supply for air. Primary air is supplied to the burner, and its flow may be measured. Secondary air enters through openings in the front end and is rarely measured. The primary air makes up only about 20% of the total air. Some experts feel that primary air should be adjusted only to guarantee that the flame shape is satisfactory. The shape of the flame is readily discernible to well trained operators through openings in the front end of the kiln.

The diagram shows one additional controller: draft. Draft is measured at the front end of the kiln and adjusted by varying a damper on the inlet of the "id fan". The draft at the point of measurement might be 30 thousandths of an inch of water. If it were to drop to only 5 thousandths, the safety trip would cut fuel because of the danger that the flame would blow back out.

The figure shows a temperature sensor at the back end of the kiln. This sensor measures the temperature of the gases leaving the process. Temperature at that point are about 400°F. The figure also shows an oxygen analyzer on the exit gas stream. This sensor is crucial for proper kiln control and also serves as a safety indicator. It is essential that the fuel and air flows be such that there is some excess oxygen in the process or there would be a combustion hazard in the exit gas handling system. Commonly, the oxygen level in the kiln exhaust is about 3%.

That completes the instrumentation in this particular P&I diagram. There is one sensor omitted that is present in most kilns: a temperature sensor at the front end of the kiln. These are usually radiation pyrometers with optical parts designed to cause the sensor to read the temperature of the solids leaving the front end of the kiln. Many kilns also have one or two additional temperature sensors which are designed to measure the temperature of the solids at intermediate points in the kiln. These are usually based on thermocouples mounted in sturdy thermowells. Maintenance of such instruments is very difficult and they are often considered unreliable or are out of service altogether.

This P&I diagram does not indicate any measurement of the mud rate to the kiln. Actually, there is usually an upstream point where the flow rate and consistency of mud are measured and controlled prior to the mud filter. Often, there is some diversion of the mud between the measurement point and the kiln that detracts from the usefulness of this measurement. Also, the mud consistency sensor may not be completely reliable. Still, these provide the operator with a way to adjust the mud rate to the kiln process.

The startup and shutdown of kilns is a special subject which is beyond the scope of this discussion. However, more can be said about the common operating changes in the process. Kilns are often described in terms of different process zones. For example, at the feed end, you have a wet mud entering the process and being contacted with a relatively cool gas stream. This is the drying zone and may represent one third of the length of the
kiln. The kiln may have some special internals to assist heat transfer in this region. One favorite is the use of chain, large steel chain loops that hang from the kiln walls and contact the solids. The main idea is that the gases heat the chain and the chain heats the solids by direct contact. There may also be mechanical action that breaks up the solids into relatively small agglomerates.

The key idea is to complete the drying of the mud within the chain section and at the same time keep the temperature in the section low enough to avoid damaging the chain itself. If the mud is not completely dry when it leaves the chain section there is a risk that the solids will form large agglomerates called balls or that the solids will adhere to the kiln walls forming a ring. Balls may be too large to process through the downstream solids handling equipment. This can sometimes be corrected by having the operator manually break up the balls or remove them for disposal. Balls can get so large that there is a risk they will damage equipment in the front of the kiln such as the burner.

Rings present a different problem. The kiln process depends on unrestricted flow of the gases up the kiln. Rings increase the pressure drop in the kiln. This may result in the id fan damper going wide open when the operator seeks to maintain the gas flow in the kiln. Also, good solids may build up behind rings and alter the residence time in the kiln, possibly resulting in overburning of the lime.

Down toward the front from the chain section, the kiln is primarily involved with heating the solids to calcining temperature. It may take one third of the kiln length to raise the solids from (say) 600°F to 1600°F where the calcining reaction will proceed rapidly. Finally, in the hot end we are supplying the energy of the endothermic calcining reaction in order to drive the reaction to completion. If the heat supply is not sufficient to complete the reaction, the lime is said to be underburned. This might induce the formation of dust in the kiln which interferes with visibility of the flame and the product and the infrared sensor. If too much heat is supplied, the lime is said to be overburned. Overburned lime may not behave well in the slaking process causing the slaker operator to increase the dosage of lime. In a tight recycle process like this one, things can deteriorate rapidly.

Most operators feel they can spot a properly cooked lime by looking in the front end of the kiln. However, it is also possible to grab a sample from the front end and do a quick lab test which will determine the amount of unreacted CaCO₃ in the sample. The process of collecting and processing a sample takes about 20 minutes, so such tests are usually run no more frequently than 4 times a shift and more commonly twice or only once per shift.

If by observation of the product or by test, the operator decides the lime is underdone, she will attempt to increase the heat going into the product. This may involve increasing the fuel flow. If the move is based on a lab test it could be quantified. If it is based on direct observation, quantification is quite difficult. If the lime is overcooked, then one may want to decrease the fuel flow. Since the issue is not just how much energy is going into the kiln but rather how much is actually getting to the solids in the calcining zone, it can be argued that undercooking can be corrected by decreasing the air flow to the front end and overcooking by increasing that air flow at constant fuel flow.
Besides the issue of meeting the lime quality objectives, the operator is trying to make sure that the drying operation in the back end of the kiln is going on properly. Obviously if balls are in evidence there is an indication that insufficient drying is going on. However, there may be a substantial delay between the start of an under-drying period and the actual observation of balls near the front end of the kiln. The nominal solids residence time in the kiln is about 3 hours and in this case we might also be expecting a transient period during which the kiln back end is gradually cooling down due to an insufficient supply of heat.

The back end temperature sensor is a reliable indicator of the conditions in the drying section. For example, the kiln operators may try to keep the back end temperature between 390 and 410. When it drops below that range they may increase fuel or air to get more heat to the back end. If it is done with air, it is a question of transferring heat from the front end of the kiln to the back. Air moves cannot be made directly. All that can be done is to increase the draft if one wishes to increase the air to the kiln. There will be no direct indication of the change in air flow, so the operator will be relying on a sense for the relative amount of change in draft needed to bring the back end temperature up to the desired range.

Whenever changes are made in fuel or air, there will be an effect on the oxygen in the exhaust gases. Usually, kiln operators are trained to think of the efficiency of the combustion process. The extra oxygen in the exhaust and the nitrogen that went with it all represent an energy loss suggesting that the same lime might have been made with less fuel. In mills where this is the issue, there will be a target range for the oxygen, say 1.5 to 2% in the flue. Then, whenever the draft is moved it may be necessary to also move fuel to keep in this range and vice versa.

QUALITATIVE DYNAMICS

If an operator is adjusting draft to move the oxygen into range, the effects will be seen within a matter of a few minutes. If the back end temperature is being changed with fuel or draft, the change may take up to 30 minutes to be reliably established. If fuel or air are moved to improve the solids appearance or measured residual carbonate, it may take from one to several hours for the full effect to come through.

WHY THINGS CHANGE

As usual, this is a key question. In many mills, management believes that the kiln process is quite steady and they pay little attention to it. They are more likely to perceive that the causticizing process is a problem, because it is seen as directly affecting the digesting process. Some variations in slaking are traceable to variations in the quality of the lime coming from the kiln. However, it may not be a question of the readily measurable CaCO$_3$ content. Overcooked lime will have a low residual, yet may not behave well in the slaker, going rather slowly from CaO to Ca(OH)$_2$, for example.
If the amount of makeup lime needed in the process gets large because the kiln is ringed up and cannot keep up with the slaking demands, then the kiln may get some attention.

The nature and quality of the instrumentation on the mud supply suggests that there can be undetected variability in the mud flow to the kiln. Suppose the mud flow dropped but the operator had no such indication. She might notice the back end temperature increase. This would be corrected with an air or fuel move and the resulting change in oxygen again corrected with the compensating action. While she searches for a satisfactory condition, the lime produced is varying in possibly unmeasurable ways but conceivably in ways that the slaker will notice.

The mud filter introduces variability. It is supposed to dewater to about 70% solids. Over time, the filter plugs up. When it is plugged, the operator manually cleans the filter. During the cleaning, the flow of mud to the kiln is interrupted altogether. The time between filter cleanings may be as frequent as two hours up to 8 hours or more. At filter cleaning time the mud dryness goes from its lowest level just prior to its highest level immediately after. Therefore, there will be a round of cut and try adjustments to fuel and air preceding and succeeding this event.

Over a longer time span, the character of the mud may change that will cause the backend temperature point at which ball formation starts to change. Thus, the range of operation of the kiln with respect to back end temperature may gradually change. It is known that trace elements in the mud and liquor can alter the behavior of the solids in the kiln dramatically. However, in the day-to-day world, little is known about such chemical compositions.

As rings form in the kiln, the relationship between draft and air rate changes. Therefore, adjustments in draft that worked prior to the operator's "days off" may fail upon her return. The time to compensate for a problem will increase until she becomes accustomed to the current state of the kiln.

GOALS FOR ADVANCED KILN CONTROLS

In a kiln instrumented as shown in Figure 1, the operator will be spending time adjusting air and fuel to achieve desired ranges in back end temperature and oxygen percent. Attempts to achieve automatic control of these quantities with conventional cascade controls is rarely successful, although the process design drawings frequently show such "loops" closed. So, they represent the immediate target for an "advanced" control. The oxygen part may yield direct economic payback through fuel savings if the advanced control can satisfactorily hold to a lower oxygen target without endangering safety. However, it is not always so that overall economics are optimized in this way; the reagent lime must be of good quality and that can override pure combustion economics.

Besides back end temperature and oxygen, there have been many reports of successful advanced controls that also hold front end temperature in a narrow band. It would certainly be easy to hold the output of the radiation pyrometer in a small band. However, there may be some question as to whether that really results in a uniform temperature of the exit solids, since the sensor is subject to interferences from the flame and from dust in
the kiln. The three controls above may result in smoother operation, such as reduced incidences of lost time or lowered production rate due to balls and rings.

A truly advanced control in this application should directly address the issue of the lime quality. There are occasional reports that sensors are on the horizon to automate this. Here, though, one could visualize having the operator test at two hour intervals and designing a control that would make the decision regarding adjustments. In fact, the adjustments might be made to the more abstract control variables resulting from the "lower level advanced control" discussed above. Thus, instead of trying to decide on a setpoint for the draft or fuel that will correct for the results of the lime test, one might have the advanced control adjust back and/or front end temperature setpoints.

![Figure 1. P&I Diagram of a Lime Kiln](image)

DC = Draft Controller  
DT = Draft Transmitter  
FC = Flow Controller  
FT = Flow Transmitter  
TT = Temperature Transmitter  
OxT = Oxygen Transmitter