

Mill study on improving lime kiln efficiency

KENNETH NESSELRODT, STEPHEN LEE, JOHN D. ANDREWS,
AND PETER W. HART

ABSTRACT: Optimization of the lime kiln requires an examination of the entire lime cycle. To increase the energy efficiency of the lime kiln, all auxiliary unit operations must function properly. It is also imperative that the lime and liquor in the system is of acceptable quality. We detail a kiln energy efficiency study performed by MWV Corp.'s Covington, VA, USA, mill. From a recausticizing standpoint, lime quality is much easier to control than liquor quality because liquor passes through many operations that are not under the lime kiln operator's control. Recausticizing is a fairly closed cyclical process where lime is concerned, so saturation of impurities to the point of operational issues must be considered. Specific cycle performance indicators (e.g., lime mud solids entering the kiln) must be viewed from a perspective that does not exclude their potential impact. To get a true picture of the cost of operating the lime cycle, all inputs must be considered. The four main inputs are power (electrical and fuel), fresh lime, caustic, and water.

Application: Process engineers can use this detailed troubleshooting approach to help optimize various parts of a mill.

The lime cycle is one of the most important unit operations in a kraft mill. The cycle makes it possible to recover or convert used chemicals into fresh, ready to use cooking liquor. The lime kiln is one component of this key recovery sector.

Several lime kiln operational conditions are easy to identify as sources of lost efficiency. For instance, dark green mud feeding the lime kiln indicates an obvious dregs removal problem. Frequently, buildup of nonprocess elements (NPEs) resulting from poor dregs removal in the green liquor clarifier is a major source of the green color [1,2]. Also, low consistency of the mud feeding the kiln indicates a need to increase consistency to restore optimal runnability [3]. Identifying the root causes of such problems and developing solutions are often difficult. To do so, all aspects of the kiln operation, including the choice of fuel, need to be thoroughly examined [1,4].

To increase the energy efficiency of the lime kiln, all auxiliary unit operations must function correctly [5]. It is also imperative that the lime and liquor in the system are of acceptable quality for causticizing application [6]. Lime quality is much easier to control than liquor quality because liquor passes through several operations that are not under the lime kiln operator's control [7]. Recausticizing is a fairly closed cyclical process where lime is concerned, so saturation of impurities to the point of causing operational issues must be considered. Impurities include magnesium oxide, silicas, and some other metals [1,2,4]. Impurities also can result from other, ineffective unit operations. All operations in the lime cycle can affect the amount of impurities allowed to enter the kiln.

To get a true picture of the cost of operating the lime cycle,

all inputs must be considered. The four main inputs in this cycle are power (electrical and fuel), fresh lime, caustic, and water. Also, each of the unit operations within the lime cycle must be understood. The slaker, causticizing process, green liquor quality, lime mud filters, and lime kiln need to be examined [8].

This report details a mill's effort to understand and optimize the efficiency of a 660 tons/day lime kiln operating with Andritz CD-filters. The causticizing plant lime cycle also consists of lime mud filters, a lime mud flash dryer, kiln sector coolers, an SO₂ scrubber, and an electrostatic precipitator. The causticizing plant liquor cycle (downstream of gravity green liquor clarification) consists of a slaker with a direct contact steam heater and three causticizers in series. Each of the major unit operations is reviewed for potential runnability impact, and some generalized findings from the mill study are addressed.

UNIT OPERATIONS

Slakers and green liquor quality

The slaker is designed to add lime (CaO) to the green liquor obtained from green liquor clarification. The slaker has three main functions:

1. Mix burnt lime with water to create hydrated lime (CaOH).
2. React hydrated lime with green liquor to make white liquor (partially causticized at this point).
3. Remove grits (impurities or burnt lime particles that don't break down in the mixture and settle to the bottom) from the mixture.

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The slaker hydrates lime to calcium hydroxide, starts the causticizing reactions, and removes dead load from the reaction system. Inputs into the slaker include green liquor (+impurities) obtained from the green liquor clarifier or clarified green liquor storage tank, reburnt lime (+impurities), fresh lime (+impurities), and calcium carbonate. Outputs from the slaker include partially causticized white liquor, hydrated lime, lime mud, heat, and grits.

From the slaker, the green liquor-lime suspension passes into the causticizers (a series of stirred tank reaction vessels) to allow residence time for the causticizing reaction to proceed closer toward equilibrium.

For the slaker and causticizers, adding excess CaO (overliming) can cause dewatering issues. Overliming results in finer particles that can blind lime mud precoat filters, resulting in poor precoat surfaces, and ultimately lead to poor filtrate separation. As a rule of thumb, the causticizing efficiency (CE) percentage at the last causticizer should read no more than 83% for good filterability. The CE% can obviously be run higher if effective alkali (white liquor strength) is suffering, but to do so for long periods can be costly.

The green liquor feed to the slaker can also be a source of undesired materials (impurities). If impurities in the form of dregs in the green liquor coming from the clarifiers and green liquor tanks are excessive, the result will be poor lime mud filtering. This is partially due to the fine consistency of the dregs and also, potentially, to dispersant qualities of the impurities in the lime mud.

The hydraulic retention time of the slaker is important to the overall performance of the recaust and kiln cycles. If the flow through the slaker is too high, it can cause some of the grit particles that would have otherwise settled in the classifier to carry over into the causticizers. Because there is no purge from the causticizers except for some evaporative losses, grit will be incorporated into the lime mud from the CD filters and impede lime quality and filterability.

Green liquor quality

Usually two items of great importance will affect recaust operations when it comes to green liquor: (1) suspended solids and (2) low total titratable alkali (TTA) strength. If there are significant dregs in the green liquor, the lime mud captured from recausticizing can become contaminated quickly enough that normal wasting strategies will not provide for adequate lime quality. More experienced operators know when dregs carryover is high enough to cause operational problems in the recaust area. If the TTA of the green liquor is not high enough to make good white liquor, the recaust operation will attempt to compensate by overliming to try and boost the effective alkali to the pulp mill.

Green liquor quality can significantly impact lime mud solids. If the green liquor feeding the slaker contains a substantial amount of dregs, the lime mud produced in the recausticizing operation will be full of impurities that can make it extremely difficult to filter and dewater the resulting lime

mud. The particles can blind small openings in the mud filter and in some cases act as a dispersant, making it hard for lime mud to bond to itself and form a filter cake.

If the green liquor feeding the slaker is low in TTA, the operational tendency is to increase the amount of lime feed to the slaker to increase effective alkali. As discussed in the previous section, it is not uncommon to slightly overlime the slaker; this occurs at around 83% CE [9]. At this point, the reaction between the hydrated lime and sodium carbonate slows and large quantities of hydrated lime are required to force the reaction any further. Unreacted hydrated lime as a result of overliming will cause difficulties in lime mud dewatering. Like dregs and other impurities, the hydrated lime will blind the filter cake and make it hard for the lime mud to dewater on the filter.

Burnt lime quality

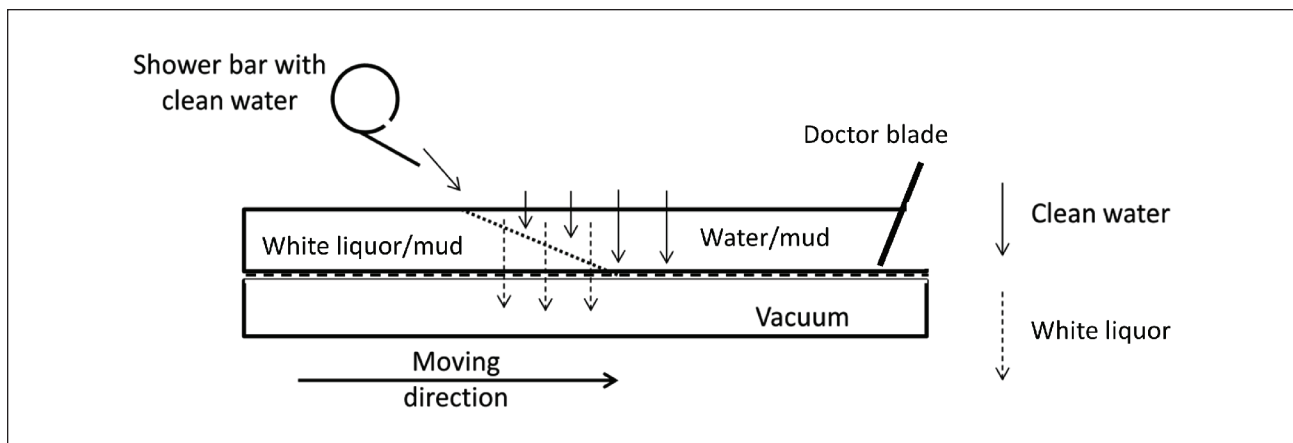
In most cases, fresh lime is a major source of impurities, though it is possible for reburnt lime to be more contaminated than fresh lime. Magnesium has been routinely identified as an NPE that originates from fresh lime into the mill system; it has been linked to filtering problems resulting in decreased lime mud solids going into the kiln. Decreased mud solids require more fuel to evaporate the excess water, resulting in significant operational expense. Other major contaminants are silica and phosphorous [1,2]. These impurities in all their combinations can substantially reduce lime mud solids. Many of these materials can exhibit dispersantlike qualities that cause the lime to lose its affinity for itself.

Reburnt lime quality can be affected by impurities that are not able to be separated from the mud that travels through the kiln back to the slaker, or by underburnt lime. Routinely, lime is purged from the system by sending it to the dregs filter to reduce NPE buildup. In most cases, the classifier screw on the slaker catches most of the impurities in the process; however, depending on the rate of addition of impurities, this method has been found to be insufficient at times of high NPE input into the system (i.e., upset conditions).

Causticizers

Causticizers are a series of stirred tank reactors designed to provide mixing and retention time for hydrated lime slurry to contact sodium carbonate remaining in partially causticized white liquor. Partially causticized white liquor, hydrated lime slurry, and lime mud are passed from the slaker to the causticizers. Causticized white liquor slurry is produced from the causticizing process.

Some evaporative losses occur so it is important to monitor causticizing efficiency across the recausticizing process to ensure the reaction is proceeding as desired and the proper amount of lime is being added to the slakers. In general, causticizers have little to do with lime mud solids. One infrequent occurrence may be an agitator that fails on a causticizer and does not provide adequate mixing for the liquor and hydrated lime slurry.



1. Simplified white liquor (WL) filter principle of operation.

CD filters

The CD filters are another link in the chain to efficient kiln operation. If the white liquor mixed with the lime mud slurry from the last causticizer is not separated, the chemical is effectively lost. In general, lime mud filters are used to separate alkali components from the lime mud. If the TTA of the lime mud filtrate is high, lime mud washing efficiency is typically low. Conversely, if the white liquor effective alkali is low, the lime mud generally is being overwashed or not being washed effectively. Using the correct amount of water is important to remove sodium from the lime mud because excessive sodium in the kiln can result in ring and ball formation within the lime kiln [10-12].

The CD filter is a compressed disc filter that functions in nearly the same manner as a vacuum drum filter. The only difference is that the operation is performed in a pressure vessel to minimize the amount of oxygen that comes in contact with the white liquor, as it will oxidize sulfides in the liquor.

The CD filter picks up the causticized liquor slurry on the surface of a filter disc sector and pushes the liquor through the cake. The cake removes the solids from the liquor slurry, resulting in high clarity cooking liquor. When the liquor pushes through the cake, the pressure drop is partially lost because the moisture in the cake provides a seal. Water is added to the cake surface so more liquor can be displaced through it, allowing the lime mud to stay wet and removal of residual white liquor. The water is added to displace the liquor, aiding in liquor-mud separation. In perfect displacement, water would push all the white liquor through the mud without considerable dilution of the white liquor. Only the surface of mud cut off with the doctor blade should have water in it. **Figure 1** represents an analogous drum filter, but the operational concepts are the same for a CD filter.

Poor cake wash operation

Any residual liquor left in the lime mud needs to be washed out before mud can be dried and sent to the kiln. More information on washing the lime mud will come later, but for now

we can say that the less the liquor is separated at the CD filters the more washing will need to be done downstream, resulting in lower performance of downstream processes.

Contaminated condensate

The condensate recovered from the evaporators is used for many processes in the recovery cycle. One of its applications is mud washing at the CD filters. Nevertheless, one needs to be careful. Condensate with black liquor contamination will cause poor dewatering because the black liquor will blind the filter cake on the CD filter and can contaminate the lime mud going to the mud storage tank if it is used for lime mud dilution (as it is during normal operation). As condensate conductivity begins to rise above 700 $\mu\text{mho/cm}$ and if lime kiln total reduced sulfur (TRS) emissions are elevated (due to mud contamination), the condensate should be diverted. The exception is CD filter cake wash and if conductivity is over 1000 $\mu\text{mho/cm}$, it may be pertinent to isolate the showers and rely on dilution for washing until upset conditions are over.

Doctor blade distance, angle, and sharpness

The doctor blades that cut the lime mud from the discs of the CD filter can be manually set for cake (mud) cutting. Normally, mills have a tendency to run the doctor blades tilted out to avoid damaging filter bags on disc sectors. A thick cake is harder to filter through and although this can result in clearer liquor, it can also result in higher liquor content in the lime mud that is cut from the cake and requires more washing. The angle and sharpness of the doctor blade can cause compaction of the filter cake, removing porosity that is required for filtering and ultimately acting as a thicker cake.

Diving, short blows, and long blows

The surface of the filter cake on each sector is renewed when the level of the CD filter vat climbs to a certain setpoint, or if it reaches a certain period before the vat level climbs. To renew the surface, the doctor blades dive in toward the cake, cutting the top layer off. A short blow will drop some mud

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soaked with liquor into the lime mud chute, causing the need for more mud washing. A long blow will cause most of the mud contamination as the vat is drained directly to the mud chute. Nevertheless, blows are required for stable CD filter operation.

Particle size

CD filters deliver very good white liquor quality (high clarity) in comparison to other methods of separation. The particles filtered in the CD filter that are not captured by other methods are in general smaller. Small particles do not settle well (white liquor clarifiers) or filter well. CD filters, nonetheless, do a good job filtering these particles out of the system.

Lime mud filters

Lime mud filters are used to remove the remaining liquor from the lime mud and clean and dry mud before entering the lime kiln. It is desirable to dry the lime mud as much as possible without causing dusting in the kiln so that energy from the burner will be used for preheating the lime mud and calcination instead of evaporating water. Lime mud filters also oxidize remaining sulfur compounds in the mud, thus reducing TRS emissions from the kiln. Mud filters take lime mud slurry (+impurities), lime mud dilution, and shower water to produce a low TTA filtrate called weak wash and high solids lime mud (+impurities).

Drum speed

Drum speed can be adjusted to allow more oxidation after the cake is washed, as well as allow more time in the wash zone to displace more soluble chemical from the lime mud cake. Slowing the drum will allow the precoat to pick up a thicker lime mud cake, increasing resistance to flow of both shower water and chemicals leaving the cake. This is a factor that must be optimized but will not typically cause major issues if it is not manipulated.

Shower water

The amount of shower water used to displace the remainder of soluble chemical in the lime mud cake has a large impact on the solids discharged from the lime mud filters. Looking at the back of the lime mud precoat filter at the shower zone, the water spraying on the cake should not bead up. Instead, it should be pulled through the cake with little resistance. If the cake is blinded, too much water is being used for shower water, or there is not adequate vacuum available, and beaded shower water will be present on the cake surface.

The shower nozzles should be checked frequently to make sure they are not plugged. Although obvious, this point is often overlooked. While solids are generally not directly affected by plugged showers, the amount of water used in the showers is sometimes increased and causes the lime mud precoat filter discharge to be wetter.

Another variable on shower water is temperature. In general, it is assumed the hotter the water feeding the shower

system the better because the viscosity of the water used to wash the filter cake is reduced. Nevertheless, if the temperature is too high the water in the system can flash to steam (system is under vacuum inside the drum), which can obviously cause flow restrictions. Flashing may be identified by loud noises heard in the filtrate separator.

Feed solids

Feed solids to the lime mud filters are controlled by using specific gravity measurements. The solids feed to the lime mud filter should be between 22%-27% for optimum dewatering. This is somewhat counterintuitive as one would imagine the lime mud feed should be as dry as possible. Because this type of filter uses the slurry feed as a filtering media in the form of a precoat, the slurry needs to have enough volume so that a structure can be formed for this precoat. If the percent solids feed is too high, there will be less porosity to the cake for the filtrate to permeate through in the precoat.

Filter wire cleanliness

Over time the filter wire on the vacuum drum will become blinded. This should be taken care of by the continuous precoat renewal system (CPR) in most situations. When lime mud filter solids decrease and vacuum increases, and there is no other obvious culprit, it is possible that the filter wire may need an acid wash. This is accomplished by feeding a 2%-4% solution of felt wash (organic acid) or an equivalent to the lime mud filter.

CPR operation

The CPR system is used to remove and refresh the lime mud precoat used as a filtering media. The medium pressure pass of the system is used to remove approximately half of the precoat and is the primary mode of operation. Every so many passes, the CPR can be set to run a high pressure pass, removing the cake to the filter wire surface. This can decrease solids discharge, as the vacuum in the drum is decreased because the bare filter wire becomes the path of least resistance; therefore, the cake is not dried as well.

Doctor blade depth, angle, dulling, and heel buildup

The doctor blade distance from the filter drum directly affects the thickness of the precoat. It is obvious that this precoat, if too thick, will not allow filtrate to flow through the cake well. If the precoat is too thin, there is a risk of running the doctor blade into the filter cloth or filter cloth grid support.

The doctor blade angle can gouge or smooth the precoat as it cuts, causing compression that acts like blinding on the precoat. There is also a characteristic buildup behind the doctor blade at the heel. The buildup in this area will cause compaction on the cake. The vat below the doctor blade should be checked frequently for mud buildup, and the showers behind the doctor blade run should be run periodically to avoid the same.

GENERAL FINDINGS

The two main properties of the lime mud entering the kiln that gain the most attention are solids and, indirectly, residual alkali. TRS plays an important role in solids discharge, as one is often sacrificed for the other. In general, high TRS will result in an attempt to overwash lime mud. This usually occurs at the lime mud filter in the form of increased shower water flow to the filters but can also occur in dilution at the lime mud filter feed pumps, mud dilution at the CD filter, or cake wash at the CD filter (results in lower effective alkali).

Recently in the Covington, VA, USA, mill, high solids feed-specific gravity to the filter has caused overwashing at the showers. This was characterized by a bead of water across the filter just above the top shower bar.

In pursuit of the cause of lower solids discharge from the lime mud precoat filters, it was mentioned that the mass flow to the kiln had at one time been altered significantly due to a recalibration of a specific gravity instrument. To regain stability in lime kiln operations, solids measurements were taken on the feed to the lime mud filters and the DCS calculation was changed to match the solids measured entering the lime mud filter. Several samples were taken and analyzed for solids versus specific gravity over the course of time, but unfortunately these measurements had the same flaw as those used to calibrate the specific gravity instrument. The glass graduated cylinder used in the lime kiln bunker lab read high by 3-5ml. This caused the mass flow calculation for the kiln to be off by as much as 7% at times.

Operators often mentioned that the specific gravity range of 1.16-1.21 would have been used in the past, depending on TRS to achieve high solids discharge, whereas running in this range with the poorly calibrated instruments resulted in solids feed percentages well over 30%, which is out of the optimum range (22%-27%). This is one reason for poor dewatering as it resulted in high TRS and, therefore, higher amounts of shower water flow. The formulas used to calculate lime mud filter solids before and after the DCS calculation was changed and can be seen as follows in Eqs. (1) and (2).

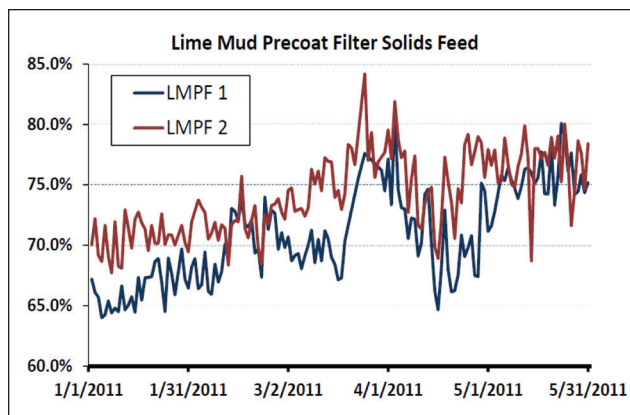
Before formula manipulation:

$$\begin{aligned} \text{Solids}(S.G.)_{Pre-2008} &\approx \frac{145 * S.G. - 145}{S.G.} + 2 \\ \text{Solids}(1.16)_{Pre-2008} &\approx \frac{145 * (1.16) - 145}{1.16} + 2 = 22\% \\ \text{Solids}(1.21)_{Pre-2008} &\approx \frac{145 * (1.21) - 145}{1.21} + 2 = 27.2\% \end{aligned} \quad (1)$$

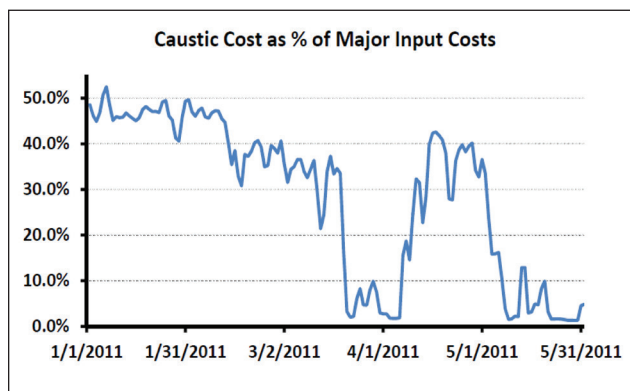
After formula manipulation:

$$\begin{aligned} \text{Solids}(1.16)_{Post-2008} &\approx \frac{145 * 1.16 - 145}{1.16} + 12 = 32\% \\ \text{Solids}(1.21)_{Post-2008} &\approx \frac{145 * 1.21 - 145}{1.21} + 12 = 37.2\% \end{aligned} \quad (2)$$

Another major factor affecting lime mud filter performance is cleanliness of the filter cloth, supporting grids, and vacuum ports in the drum. Using a mild organic acid solution to clean



2. Lime mud precoat filter solids. A step-change increase in solids can be seen in mid-March due to acid cleaning of the lime mud filters.



3. Estimated caustic cost as percentage contribution to cost per ton of reburnt lime produced at fixed costs.

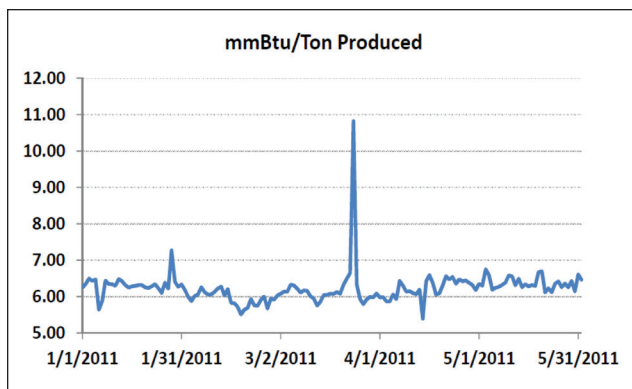
the filter resulted in a step change in filter discharge solids in the March 2011 No. 1 Recovery Unit outage week as seen in **Fig. 2**. Despite process changes, it seems fresh lime source and makeup rate have more impact than any other factor on the cost of operating the recausticizing plant. Lime inventories can be replenished more quickly using a good fresh lime source without having a negative impact on lime mud filter solids discharge, and more importantly, without necessitating the overuse of caustic in the lime kiln SO₂ scrubber.

A 60-day trial of supplier A lime for fresh makeup to the recausticizing area began February 1, 2011. Process improvements across the board were seen during this period, although a few of the previously mentioned process changes helped unlock the full potential of the high purity source. It took several weeks before there was an observable change in appearance of the lime in the system.

During April 2011, supplier A had an outage and could not supply the recausticizing plant with lime. For this month, a sharp decrease in solids can be seen (Fig. 2). **Figure 3** shows a sharp increase in caustic usage on the SO₂ scrubber.

Reducing caustic usage at the kiln has obvious raw materials connotations, but even when soda losses are high and large amounts of caustic are needed for makeup, it is

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4. Fuel cost per ton reburn produced. A slight decrease can be seen throughout the duration of the initial 60-day Carmeuse fresh lime trial.

better to have the capability to intentionally make up or lose chemical inventory. When scrubber use is high, it is for environmental reasons, not chemical makeup; over time, this causes less liquor storage flexibility in a limited capacity area. When inventories are intentionally reduced to a more manageable level, there is a buffer between pulping and recovery that reduces process instability due to upstream or downstream upsets. Furthermore, high chemical inventories increase the risk of environmental excursions, as there is more likelihood of spills while juggling inventories.

Figure 3 shows the cost of caustic used in the SO₂ scrubber per ton burnt lime produced. The reduction in cost is not all

savings (caustic needs to be added to the system to make up for losses), but a reasonable cost per ton on a high production day using this approximation would be 40%–50% of the higher operating costs in Fig. 3 to hold constant inventory. The inability to reduce inventory is a cost opportunity.

A crude model for estimating kiln operating inputs, along with a crude model for estimating lime cycle, was developed to assist in this analysis. Although the model uses fixed costs for the estimation, it could be modified easily for variable costs.

As solids feed to the kiln have increased, reductions in MMBtu/ton of product have been seen but not sustained. Estimations of MMBtu/ton have not been accurate since the calculation change in 2008 for mass flow through the kiln, but they should at least show relative changes. **Figure 4** shows the changes in cost of fuel for tons produced during the last few months of this study. Changes in energy input were relatively mild but before returning to supplier B as a fresh source during April, increase in MMBtu/ton was approximately 0.5.

There are two items not yet mentioned that lend to successful filtering operations. The first is using progressively cleaner water sources through the wash cycle. Condensate should be used for cake wash and mud dilution at the CD filter, softened water from the filter building reclaim sump for mud dilution at the lime mud filter feed pumps, and filtered water for the cake wash showers at the lime mud filters. It may also be possible to shift the drying–wash zones on the lime mud filter drum by throttling the top shower bar back so the zone

ABOUT THE AUTHORS

We chose this research topic because the lime kiln–recaust cycle of our mill was not performing to desired specifications. The underperformance was causing production difficulties and increased operating costs. An effort to optimize performance was undertaken to correct these operational and cost challenges.

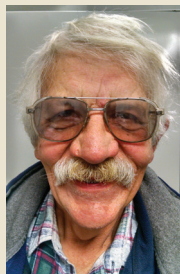
Our work is an applied optimization study that employed theoretical and operating conditions supplied by other studies. An interesting aspect of this work is the documentation and justification of the detailed, systematic approach used to optimize the process.

The number of interrelated processes associated with the entire lime kiln–liquor cycle provided a significant number of relatively subtle interactions that may or may not have had an impact on optimization. All of these interactions had to be investigated.

In the end, we found that a graduated cylinder that had been used for several years was significantly in error and thus mill test results were not accurate. The use of inaccurate results for routine control resulted



Nesselrodt



Lee



Andrews



Hart

in suboptimal process operation. It was surprising that something as mundane as an inaccurate graduated cylinder could upset the entire lime–recaust cycle.

Young process engineers who seek to optimize their specific mill processes may benefit from the detailed, systematic approach we outlined. The next step is to monitor and maintain the improved mill operations.

Nesselrodt is shift operations manager and Lee is recovery engineer, MWV Corp., Covington, VA, USA. Andrews is senior corporate engineer, MWV Corp., Charleston, SC, USA. Hart is director, Fiber Science, MWV Corp., Atlanta, GA, USA. Email Hart at peter.hart@mwv.com.

that allows for drying of the cake and oxidation of sulfur compounds can be made larger.

CONCLUSIONS

Unfortunately, no one magic value to change, knob to turn, or chemical additive has been found to increase lime mud solids feeding the kiln. Instead it seems that mud solids, as with other values such as effective alkali and causticizing efficiency, is a general health indicator of the recausticizing process. Because the lime cycle is as near a closed loop as we can make it, any one unit operation in the lime cycle can cause issues with the rest. The slaker, causticizers, CD filters, and lime mud precoat filters all have a great deal of influence on the amount of energy and raw materials needed to calcine lime mud. Fresh lime makeup has been found to be a significant source of NPEs and result in low mud solids (high fuel demands) in the lime kiln. Instrument calibration and maintenance are also significant sources of operational variability and operational cost. As with most reasonably closed cycles within the mill, it is important to maintain the health of the entire cycle to optimize the process and have an efficient operation. **TJ**

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