VARIABILITY IN LIME-MUD FEED RATE INDUCED IN THE LIME-MUD FILTER: CONSEQUENCES AND ACTIONS

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VARIABILITY IN LIME-MUD FEED RATE INDUCED IN THE LIME-MUD FILTER: CONSEQUENCES AND ACTIONS

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ABSTRACT

This study shows that despite keeping both lime-mud slurry flow and density constant, lime-mud moisture content and feed rate from the filter to the lime kiln can vary significantly. These variations, which were previously not detected in the mill, were revealed after installation of a band scale and a moisture detector. It was found that cleaning the doctor blade caused a periodic disturbance in the lime-mud feed rate to the kiln. The variations in moisture content, however, were too minor to disrupt the stability of a kiln equipped with a flash dryer. This work resulted in a new and better way of continuously estimating available CaO and reburned lime production rate.

INTRODUCTION

The present investigation was carried out at Södra Cell Mönsterås, Sweden. The mill produces 750,000 ADt of fully bleached Kraft pulp per year. The mill produces softwood and hardwood pulp in campaigns that are around 25 and 10 days long, yielding 550,000 ADt softwood pulp and 200,000 ADt hardwood pulp.

The mill has two lime kilns equipped with lime-mud flash dryers. Both kilns are fired with approximately 70% pulverized bark and 30% tall-oil pitch. On rare occasions, the kilns are fired with 100% fuel oil. Kiln No. 1 is 113 metres long, has an inner diameter of 3.3 metres, and produces 450 tons/day of reburned lime. Kiln No. 2 is 73.5 metres long, has an inner diameter of 2.8 metres, and produces 250 tons/day. Kiln 1 is equipped with a labyrinth cooler, and kiln 2 has satellite coolers. The calculated adiabatic flame temperature is about 1800°C for dry bark fuel, and the flue-gas temperature is about 700°C at the lime-mud feed end.

Table 1 gives a mill balance for chemical recovery. The amount of lime needed for the desired alkali production is around 0.28 ton of reburned lime per ADt. However, the reburned lime production figure from the mill data system is 0.32 ton of reburned lime per ADt. A dump test (all reburned lime was taken out and weighed during 30 minutes) was performed to validate the signal from the mill data system. The result was that the mill data system showed an overestimation of around 4.3% (0.306 ton/ADt instead of 0.32). Accordingly, there seems to have been an error in how the reburned lime production was calculated.

The production rate of available CaO is important for the performance of the white liquor preparation plant. An overcharge of available CaO to the slaker results in overliming, which is known to impair lime-mud filterability and cause severe white liquor production disturbances and even pulp production shutdowns [1]. The production rate is required to regulate fuel demand because steady state is first reached around 90 minutes after a production change. Fuel demand after a production change must be estimated using the production rate. This is even more important when using a lime-kiln control strategy. Lime calcination requires 3 MJ/kg of formed CaO at 900°C [2] plus additional heat for bringing the system up to temperature. A heat and mass balance at Södra Cell Mönsterås indicated that drying of lime mud requires around 1.5 MJ/kg. The heat losses through the kiln shell were around 1.1 MJ/kg, and the losses with the hot flue gas to the electrostatic precipitator were

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TABLE 1 *Mill balance giving an estimate of effective alkali and CaO demand calculated from pulp production.*

Object	Number	Units	Calculation
Pulp production	2,150	ADt/day	Indata, weighed
Effective alkali to digester (as NaOH)	20	% on dry wood	Indata, flow meter
Effective alkali to white liquor oxidation	40	kg/ADt	Indata, flow meter
Sulphidity (on active alkali)	38	%	Indata, titration
Available CaO	87	%	Indata, laboratory analysis
CaO in lime mud	1.5	%	Indata, laboratory analysis
Pulp yield, fully bleached	45	%	Indata, calculation
Pulp production	1,935	BDt/day	2150 × 0.9
Wood demand	4,300	tons dry wood/day	1935/0.45
Effective alkali to digester (as NaOH)	860	tons/day	4300 × 0.2
Total EA demand	946	tons/day	860 + 40 × 2150/1000
NaOH demand	724	tons/day	2 × (1-0.38) × 946/(2-0.38)
NaOH demand	18.1	Mmol/day	724 / 40
Ca(OH)$_2$ demand	9.1	Mmol/day	18.1 / 2
CaO demand	9.1	Mmol/day	18.1 / 2
CaO production	507	tons CaO/day	9.1 × 56
Reburned lime production	585	tons lime/day	507/0.87
Reburned lime for overliming	15	tons lime/day	585/0.57* × 0.015
Spec. CaO demand	0.24	tons lime/ADt	507/2150
Spec. reburned lime demand	0.27	tons lime/ADt	585/2150
Spec. reburned lime demand (with 1.5% CaO in mud)	0.28	tons lime/ADt	0.27 + 15/2150

*0.57 is a factor for converting lime mud to reburned lime, assuming that 50% of the dead load in the lime mud remains in the reburned lime. See Table 2 for more details on this calculation.

around 1.4 MJ/kg of reburned lime product (total 7 MJ/kg reburned lime). It is of the utmost importance to keep the lime-kiln temperature profile stable over time because temperature fluctuations are known to cause recarbonation of the rings in the lime kiln [3]. Furthermore, performance variations in the lime-mud filter are known to influence reburned lime quality [4,5].

This paper proposes a new procedure for calculating reburned lime production. This calculation requires measurements of mass flow, moisture content, and carbon content of the lime mud and the reburned lime. Södra Cell in Mönsterås invested in a band scale, an NIR detector, and a carbon content analyzer to set up this new calculation procedure and to achieve better control of some of the process parameters affecting reburned lime production. After the band scale and the NIR moisture detector were installed, fluctuations in lime-mud production and moisture content were noted, and a more detailed

study of the reasons for and consequences of these fluctuations was performed.

CALCULATION OF REBURNED LIME PRODUCTION

Old Procedure

The conventional way to calculate lime production uses the volumetric flow rate q and the density of the lime-mud slurry that is pumped to the lime-mud filter. The volumetric ratio, *y*, is calculated using the linear equation, $y = kx + m$, where the slope coefficient, *k*, is inside brackets in Eq. (1). The density of the solid material in the lime mud is denoted as ρ_{mud}, and the filtrate density is denoted as $\rho_{filtrate}$. The constant *m* is obtained by setting the slurry density ρ_{slurry} equal to ρ_{mud} with *y* equal to 100%:

$$y = \left(\frac{1}{\rho_{mud} - \rho_{filtrate}} \right) * \rho_{slurry} + m. \quad (1)$$

Equation (2) shows a common calculation of lime production. The ex-

pression inside brackets gives the volume fraction of lime mud in the slurry. The factors 24 and 3.6 are used to convert kg/s to tons/day:

$$Reburned\ lime\ production =$$
$$q * \left(\frac{\rho_{slurry} - \rho_{filtrate}}{\rho_{mud} - \rho_{filtrate}} \right) * \rho_{mud} * Conversion$$
$$factor * 24 * 3.6. \quad (2)$$

The lime mud-to-reburned lime conversion factor is calculated by adding the parts of the reburned lime together as in Eq. (3):

$$Conversion\ factor = Dead\ load\ prod. +$$
$$CaO\ prod. + Residual\ CaCO_3\ prod. \quad (3)$$

If the conversion factor is set to 0.6 (corresponding to around 93% $CaCO_3$ in lime mud and 3% residual $CaCO_3$ in reburned lime), ρ_{mud} is set to 2 717 kg/m³, and $\rho_{filtrate}$ is set to 1000 kg/m³, Eq. (2) can be simplified to Eq (4), which is

the calculation used in the mill data system at Södra Cell Mönsterås:

$$Simplified\ reburned\ lime\ production =$$
$$q * \left(\frac{\rho_{slurry}-1}{0.632}\right) * 0.6 * 24 * 3.6. \tag{4}$$

New procedure

Analyses show that the conversion factor (g reburned lime/g lime mud) in Eq. (3) can vary between 0.55 and 0.59, with an average of 0.57 during normal conditions (a simple improvement would be to substitute 0.6 for 0.57). Analyses of 11 different samples of lime mud after the filter gave an average solid material density of 2600 kg/m^3 with a standard deviation of 18 kg/m^3. This is taken into account when calculating the reburned lime production (tons/day) in Eq. (5) as the sum of the calculated CaO, the remaining dead load, and the residual CaCO$_3$ in the reburned lime:

$$Reburned\ lime\ prod. = CaO\ prod.$$
$$+Dead\ load\ prod. +Residual$$
$$CaCO_3\ prod. \tag{5}$$

CaO production in Eq. (6) is calculated from the dry lime-mud feed rate, $\dot{m}$ (tons/hour), multiplied by a factor including calcination degree, cd (explained in Eq. (7)), and the CaCO$_3$ in the mud plus the CaO already present (from overliming) in the mud. The factor 24/1000 is used to convert kg/hour to tons/day. The CaCO$_3$ in the mud is calculated from the carbon content in the mud under the assumption that all carbon is present as calcium carbonate. The factor 56/100 is the molar weight of CaO divided by that of CaCO$_3$. The dry lime-mud feed rate is calculated using the moist lime-mud feed rate and the moisture content:

$$CaO\ production = \dot{m} \times \left(CaCO_{3mud}\right.$$
$$\left. * \frac{cd}{100} * \frac{56}{100} + CaO_{mud}\right) \frac{24}{1000}. \tag{6}$$

Two equations are required to derive the calcination degree. First, it is assumed that dry lime mud consists of CaCO$_3$, CaO, and dead load (the balance). The second equation results from assuming that the residual CaCO$_3$ in the reburned

lime can be calculated by subtracting the equivalent CaCO$_3$ that was converted using the calcination degree from the original CaCO$_3$ in the lime mud. This gives an expression for residual CaCO$_3$ in reburned lime as a function of calcination degree, CaCO$_3$ in lime mud (actual carbon in lime mud), and CaO in lime mud. Table 2 presents the concept of the derivation.

After some rearrangements, an expression is obtained for the calcination degree as a function of residual CaCO$_3$ in reburned lime, CaCO$_3$ in lime mud, and CaO in lime mud, as shown in Eq. (7). DL represents the assumed dead load in the lime mud that remains in the reburned lime.

An analysis of the relative influence of the different components presented in Fig. 1 shows that the CaO in mud has practically no influence and can be neglected. Equation (7) can then be simplified to Eq. (8).

The dead load production (tons/day) used in Eq. (5) is calculated in Eq. (9) using the dead load in the lime mud and the

$$cd = \frac{CaCO_{3mud}*100*100+RCaCO_{3lime}*CaCO_{3mud}*DL+RCaCO_{3lime}*CaO_{mud}*10*DL-RCaCO_{3lime}*1000*DL-RCaCO_{3lime}*CaO_{mud}*10*100-RCaCO_{3lime}*CaCO_{3mud}*100}{(CaCO_{3mud}*100+CaCO_{3mud}*56*RCaCO_{3lime}/100-CaCO_{3mud}*RCaCO_{3lime})} \tag{7}$$

TABLE 2 *Derivation of an expression for residual CaCO$_3$ depending on calcination degree. This expression can then be rearranged and used to compute the calcination degree, as shown in Eq. (7).*

| *Assumptions*			
Calcination degree	98.1	%	Initially assumed
NPE remaining in lime	50	%	Empirically determined, explained further on
Indata			
Residual CaCO$_3$ in lime	3.0	%	Not used in starting balance
CaO in lime mud	1.5	%	Laboratory analysis
C in lime mud	10.8	%	Laboratory analysis
Lime mud balance			
CaCO$_3$	900	g/kg	10.8×10/12×100
CaO in lime mud	15	g/kg	1.5×10
Dead load (balance)	85	g/kg	1000-900-15
Total	1000	g/kg	
Reburned lime balance			
CaO from calcination	494.4	g/kg	900×56/100×98.1/100
R-CaCO$_3$	17.1	g/kg	900-900×98.1/100
CaO from CaO in lime mud	15.0	g/kg	1.5×10
Dead load	42.5	g/kg	85×50/100
Total	569.0	g/kg	494.4+17.1+15.0+42.5
Calculation result			
Calc. R-CaCO$_3$ in lime	3.0	%	17.1/569.0×100
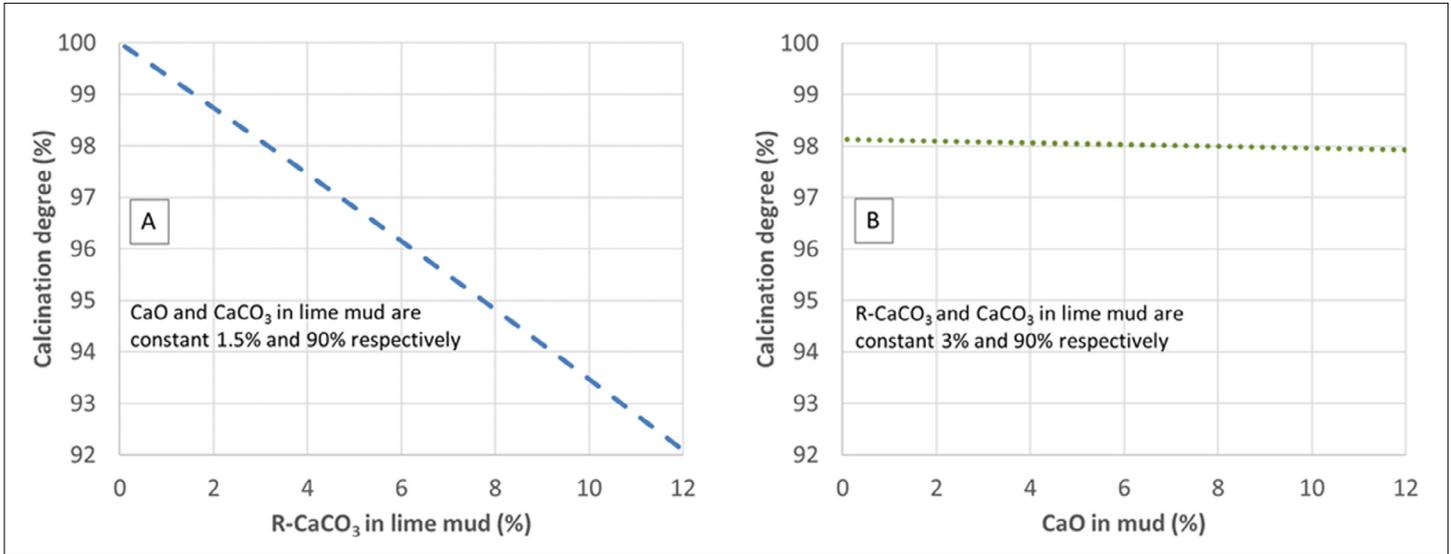
Fig. 1 - Graphical depiction of the impact of R-CaCO$_3$ (A) and CaO in mud (B) on calcination degree as calculated using Eq. (7).

$$cd' = \frac{CaCO3_{mud}*100*100+RC_{lime}*CaCO3_{mud}*DL-RC_{lime}*1000*DL-RC_{lime}*CaCO3_{mud}*100}{(CaCO3_{mud}*100+CaCO3_{mud}*56*RC_{lime}/100-CaCO3_{mud}*RC_{lime})} \quad (8)$$

fraction of this dead load remaining in the reburned lime:

$$Dead\ load\ prod. = \frac{(1000-CaCO3_{mud}-CaO_{mud})\times DL}{1000}$$
$$\times \dot{m} \times \frac{24}{100}. \quad (9)$$

The dead load in the lime mud is calculated by subtracting the CaO and CaCO$_3$ in lime mud from the total weight of dry lime mud. The residual CaCO$_3$ in reburned lime is calculated in Eq. (10) using the calcination degree:

$$Residual\ CaCO_3\ in\ reburned\ lime =$$
$$\frac{CaCO3_{mud}}{1000} * \left(1-\frac{cd}{100}\right) \times \dot{m} \times 24. \quad (10)$$

Table 3 shows an example of the results obtained by these calculations.

VALIDATION OF EXPERIMENTAL SET-UP AND CALCULATION

The band scale was a Kn4-200 instrument from SEG, Sweden, which was installed on the lime-mud conveyor belt after the filter. The band scale was calibrated with known weights on a moving belt with a deviation of 0.13%. An NIR detector from NDC Technologies, USA, was installed above

TABLE 3	New calculation of reburned lime production and available CaO. All carbon in lime mud is assumed to be present as CaCO$_3$.			
Notation	**Category**	**Value**	**Units**	**Calculation**
	Indata			
DL	Dead load in mud remaining in lime	50*	%	Assumed
q	Lime mud feed rate to filter	11.1	litres/s	Flow meter
ρ_{slurry}	Slurry density to filter	1.24	kg/litre	Density meter
	Moisture content	24.0	%	NIR or laboratory
	Wet mud feed rate to lime kiln	21.4	tons/hour	Band scale
	Carbon content in dry lime mud	10.8	%	Laboratory analysis
	Residual CaCO$_3$ in reburned lime	3.0	%	Laboratory analysis
	CaO in lime mud	1.5	%	Laboratory analysis
	Initial calculations			
	Carbonate content	9.0	mol/kg dry mud	10.8×10/12
$\dot{m}$	Lime-mud feed rate	16.3	t/h (dry weight)	21.4× (100-24.0)/100
	Lime-mud mass balance			
	CaO in lime mud	15	g/kg dry mud	1.5/100×1000
	CaCO$_3$ in lime mud	900	g/kg dry mud	9.0×100 (from molar conc. of C)
	Dead load in lime mud	85	g/kg dry mud	1000-900-15
	Sum	1000	g/kg dry mud	
	Reburned lime calculation			
cd	Calcination degree	98.1	%	See Eq. (7)
	Reburned lime mass balance			
	Dead load in reburned lime	42.5	g/kg dry mud	85×50*/100
	CaO in reburned lime	509.4	g/kg dry mud	900×98.1/100/100×56+15
	CaCO$_3$ in reburned lime	17.1	g/kg dry mud	(1-98.1/100)×900
	Mud-lime conversion factor	569.0	g lime/kg dry mud	43+509+17
	Results			
	CaO production	198.9	tons/d	16.3×509.4/1000×24**
	Dead load prod. in reburned lime	16.6	tons/d	85/1000×16.3×50*/100×24**
	R-CaCO$_3$ prod. in reburned lime	6.7	tons/d	900× (1-98.1/100) ×16.3/1000 ×24**
	Reburned lime prod. (new calc.)	222.2	tons/d	198.9+16.6+6.717.1/569.0x100
	Reburned lime prod. (old calc.)	218	tons/d	See Eq. (4)
	Calc. R-CaCO$_3$ in reburned lime	3.0	%	17.1/569.0x100
	Available CaO in reburned lime	90	%	509/569x100

*Fraction of dead load entering in the lime mud (50%) that remains in the reburned lime. See the section below for further details.
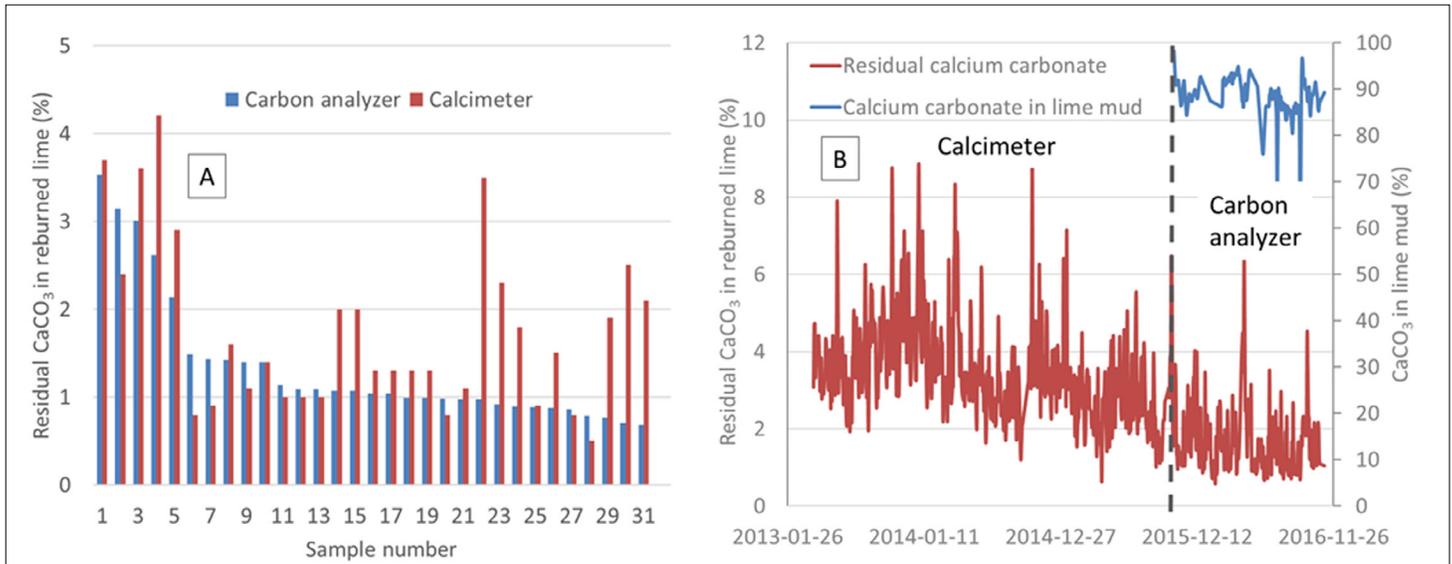**The factor of 24 converts tons/hour to tons/day.

Fig. 2 - Comparison of elemental carbon analysis and calcimeter results: (A) results from the two methods are compared in the laboratory; (B) results from the mill data system (after 2015-12-12, the carbon analyzer was used).

the lime-mud conveyor belt after the filter. The NIR measurement was validated by capturing the mud by skimming the top few centimetres of mud traversing the conveyor belt using a 2-litre wide-mouth bottle. The collected sample was assumed to have the same mud particle distribution as that detected with the NIR measurement. The results obtained showed good agreement with observations and were in accordance with previous findings from another installation [6]. An ELTRA CS-800 analyzer was used to analyze the carbon content. In this analyzer, the carbon content is determined by combustion of the solid material in an induction furnace under a pure oxygen atmosphere, oxidizing carbon to CO_2, which is detected with infrared cells. Initial concerns were that the carbon analysis would measure carbon that was not present as $CaCO_3$ and therefore would give a residual carbonate content that was too high. The traditional method for determining $CaCO_3$ in reburned lime at the mill includes acidification of a sample of reburned lime and measurement of the volume of released CO_2 (cf. ISO 10693:2014). This is referred to as the calcimeter method. As seen in Fig. 2, the elemental analysis in fact gave a lower $CaCO_3$ content than the calcimeter, implying a low risk of measurement artefacts. This is a positive discovery because

the reliability of carbon detection is excellent and the test can be done with 0.5% accuracy for carbon content.

To validate the new calculations, industrial green and white liquor samples were analyzed by ABC titration according to SCAN-N 30:85. The samples were collected and analyzed using a robot, and sampling was done approximately every 20 minutes. Na_2SO_4 and $Na_2S_2O_3$ were analyzed by an external laboratory. The

liquor composition was used to calculate the ionic strength and the equilibrium constant of the causticizing reaction [7]. The equilibrium constant was used to calculate the theoretical charge of reburned lime required to reach the measured effective alkali concentration in the white liquor. The theoretical charge was compared with the results of the new production calculation in Eq. (5) and the old calculation in Eq. (4).

TABLE 4	Comparison of old and new procedures for calculating reburned lime production with a theoretical calculation of the reburned lime charge required to reach the measured effective alkali concentration in the white liquor. Na_2CO_3 was multiplied by 1.325 and Na_2S was multiplied by 0.975 to obtain the amount as a substance. The green liquor density was measured as 1.15 kg/l at 90°C and 1.2 at 20°C. The green liquor composition was analyzed with ABC titration, and samples were collected approximately every 20 minutes. The specific periods were chosen to be stable and representative, with no purchased lime added.		
Start		2016-12-25	2017-01-15	
Finish		2017-01-01	2017-01-22	Comments
Green liquor				
NaOH	g NaOH/l	8.0 (6.2)	7.5 (5.9)	ABC titration as NaOH (Na_2O)
Na_2CO_3	g NaOH/l	108 (84.0)	105 (81.3)	ABC titration as NaOH (Na_2O)
Na_2S	g NaOH/l	36.6 (28.4)	44.2 (34.3)	ABC titration as NaOH (Na_2O)
Na_2SO_4	g/kg	8.9	8.9	Only one sample
$Na_2S_2O_3$	g/kg	5.9	5.9	Only one sample
GL feed	l/s	101	98	Flow meter
Ionic strength	mol/kg	4.63	4.68	0.5 x $\sum m$ x z^2 of all ions
Equilibrium constant	-	29.95	29.43	See [7]
White liquor				
Effective alkali	g/l	116 (88)	116 (89.9)	ABC titration as NaOH (Na_2O)
There of NaOH	g/l	98 (76)	94 (72.8)	ABC titration as NaOH (Na_2O)
Reburned lime and lime mud				
CaO in lime mud	%	0.75	1	Laboratory analysis
Available CaO	%	87	87	Laboratory analysis
Production				
Old calculation	t /d	757	677	From mill data system
New calculation	t /d	654	573	Assuming 50% of dead load remaining
Theoretical charge	t /d	602	589	Assuming overliming to reach CaO in lime mud

Fig. 3 - Comparison between laboratory analyses and predicted available CaO concentrations calculated with different lime-mud dead load fractions remaining in reburned lime.

The results in Table 4 show that for both time periods, the old calculation procedure overestimated lime production and that the new calculation procedure gave results closer to the theoretical charge.

In the calculations in Table 3, the fraction of dead load remaining, DL, in Eqs. (7) and (9) was set to 50%. To justify the choice of 50%, calculated values of available CaO at different fractions of remaining dead load were compared with results from laboratory analyses. Figure 3 shows that if this fraction is set to 100%, then the available CaO is underestimated, whereas a satisfactory fit is found when the fraction is set to 50%. A tentative explanation for dead load not being conserved in calcination could be that some metal hydroxides dissociate into metal oxides and water.

INDUSTRIAL OBSERVATIONS

Oscillations in Lime-Mud Moisture Content

When using the NIR signal to monitor the moisture content of lime mud after the lime-mud filter, variations in moisture content with a periodicity of one hour and an amplitude of 0.5–1 percentage points were found, as shown in Fig. 4. The fluctuations coincided with the movement of the water jet for precoat removal, which traversed from the right-hand side of the drum towards the left-hand side at a speed of 82 mm/min while removing old precoat with a water pressure of 6 MPa. The length of the filter was 9000 mm, and two water jets traversed on the same rack, meaning that one jet started at 0 mm and the second started at 4500 mm. When the whole length of the drum had been covered, the water jet traversed back to the right-hand side of the drum at a speed of 500 mm/min with a spraying pressure of only 0.6 MPa. The initial suspicion was that the variations were due to measurement artefacts in which the lime-mud surface was perhaps moister than the bulk flow. To investigate whether these observed variations were real, mud samples were taken every 10 minutes for two hours. The samples were taken by holding a 2-litre wide-mouth bottle and catching the mud that fell at various points on the drum. Care was taken to ensure that the
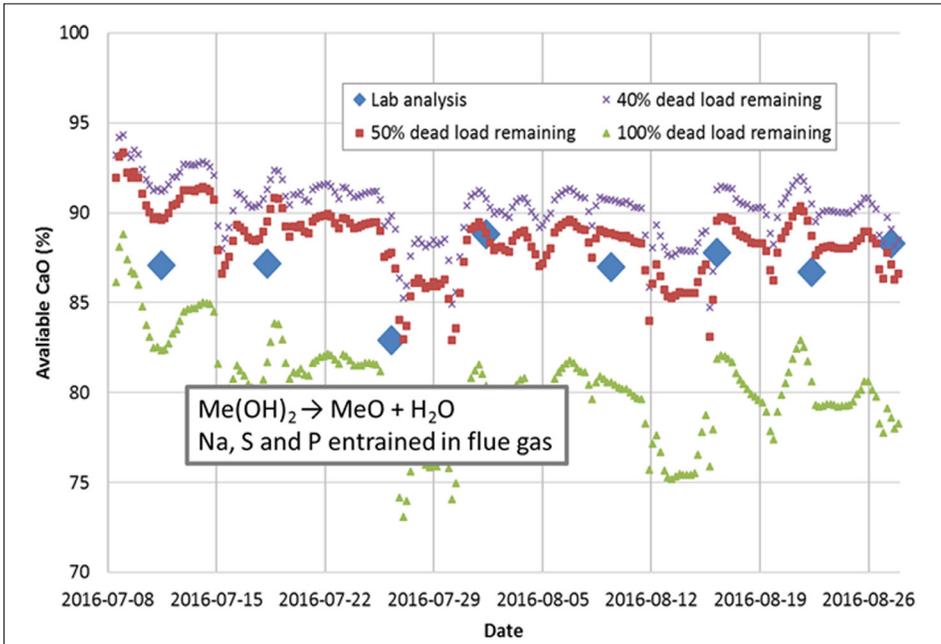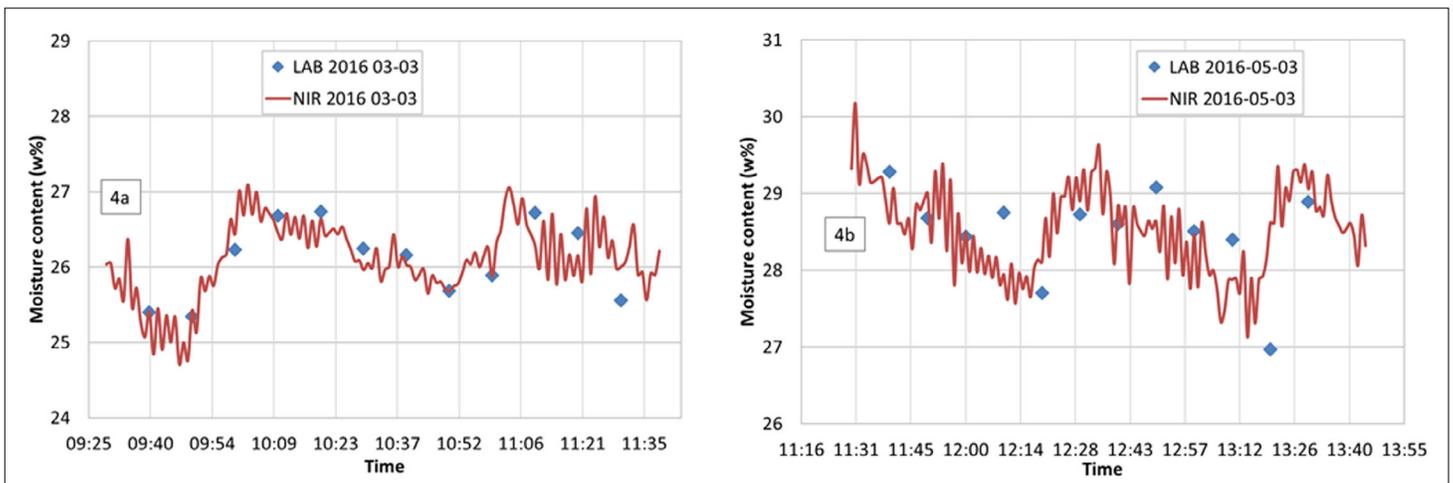

Fig. 4 - Validation of moisture content fluctuations. Samples were taken on 2016-03-03 (4a) from 09:40 to 11:30 and on 2016-05-03 (4b) from 11:40 to 13:30 from across the entire filter.
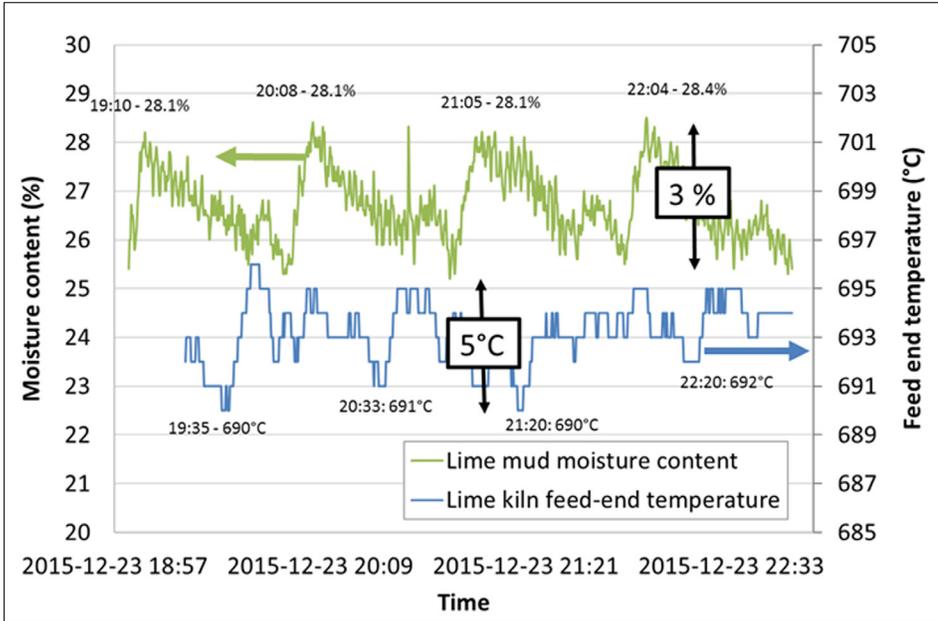
Fig. 5 - **Effect of lime-mud moisture content variations on lime-kiln feed-end temperature during stable fuel feeding (100% heating oil at 32.5 MW) and at production rate (415 tons/day).**

full length of the drum was sampled during the same length of time while filling the bottle to the same degree every time to capture a representative sample. Figure 4 shows the results, which indicate that the fluctuations in moisture content are indeed real and follow the movement of the water jet.

Effects of small variations in moisture content

Figure 5 shows a time period during which lime production was stable and the fuel supply consisted of only fuel oil and

remained constant. Data from this period show that the feed-end temperature dropped around 5°C as lime-mud moisture content increased from around 25% to around 28% (1.7°C per percentage point).

Larger variations in dry solids feed rate

After the band scale had been installed, it was noted that periods around four minutes long of increased lime-mud feed rate occurred every eight hours. An investigation of the control system showed that

the only control function with an eight-hour periodicity was a water valve that opened to wash the doctor blade (Fig. 6a). When the valve opened, the lime mud was washed away from the blade and ended up together with the wash water in the tray, thus increasing the level in the tray and the lime-mud uptake of the filter. These short periods of increased lime-mud feed were not captured using the old calculation for reburned lime production (Eq. (4)) because it used the density and volumetric flow of the slurry before the filter.

During the increase in lime-mud feed rate that started at 02:40 (Fig. 6b), an additional 118 kg of dry lime mud was introduced into the lime kiln. The consequence of this increased lime feed was a sudden temperature drop from around 700°C to 670°C in the feed end of the kiln, as shown in Fig. 6b. The reason for the temperature drop was most likely an increase in the amount of water in the lime mud. The negative spike in feed-end temperature could potentially cause problems with recarbonation due to a change in the temperature profile in the lime kiln.

Comparison with dynamic simulations

Mill data were compared with findings from dynamic simulations (Language: Modelica, simulation tool: Dymola from Dassault systems) performed by Optimation AB, Sweden. The simulations confirmed a fluctuation in feed-end temperature
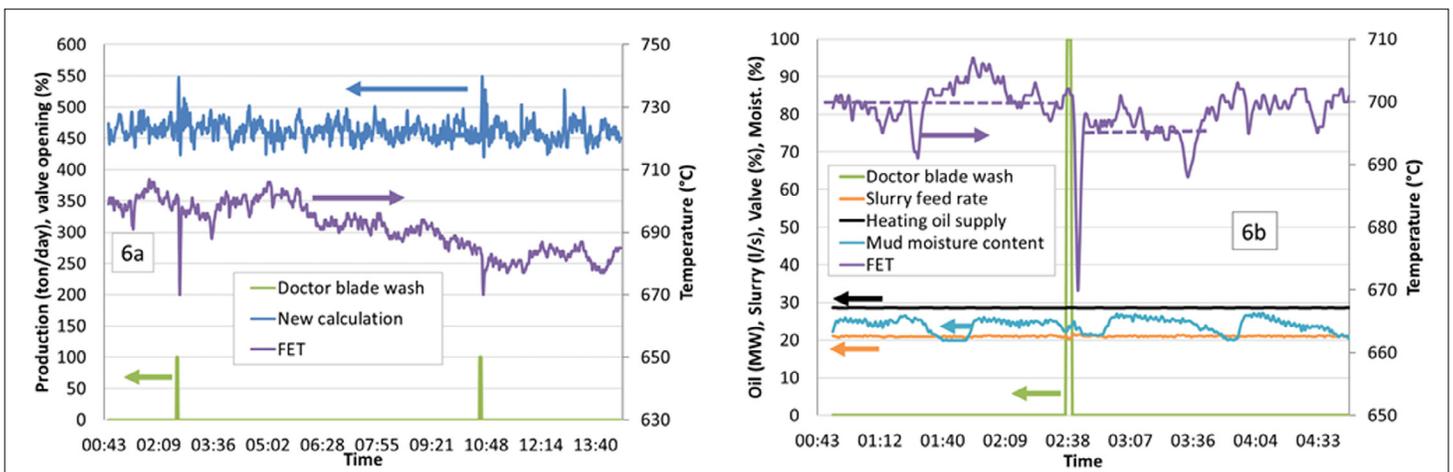

Fig. 6 - **Effect of a sudden production increase on 2016-11-19 under stable production conditions and fuel supply (100% heating oil). The new calculation refers to the production rate as described in Eq. (5). FET denotes the feed-end temperature of the lime kiln. 6b is a magnification of 6a.**

of around 3°C–5°C corresponding to fluctuations in moisture content, as shown in Fig. 5. Furthermore, the simulation also showed that even though the moisture content did indeed induce fluctuations in feed-end temperature, these fluctuations did not propagate and did not pose any problem for recarbonation in the lime kiln. The simulation of the sudden production increase shown in Fig. 6 indicates a decrease in feed-end temperature of around 5°C, which is a considerably lower decrease than was seen in the mill data, where the temperature dropped from 700°C to 670°C. However, the simulation assumed that all lime mud was carried with the hot flue gas to the flash dryer, but in reality part of the moist lime mud falls directly into the kiln feed end. This is in fact an interesting simulation application that could be used to estimate the amount of mud that falls through into the kiln feed. However, such an experiment is beyond the scope of this study and was not investigated further.

RESULTS AND DISCUSSION OF MILL TRIALS

To investigate the actions and consequences associated with the observed fluctuations in lime-mud feed rate and moisture content induced in a lime-mud filter, two mill trials were conducted using NIR measurements and a band scale.

Trial 1

During the first trial, the water flow to the tray, which was used to maintain a steady level, was shut off (Fig. 7). The purpose of the trial was to investigate how the water affected the lime-mud moisture content and feed rate after the filter. The level control was believed to cause a variation in slurry dilution and an uneven distribution of both lime-mud dry solids content and density in the tray.

However, the results show that the standard deviation in moisture content actually increased from 0.5 (average of 26.3) to 0.9 (average 26.2) percentage points when the level in the filter was not controlled. An interesting observation is that the moisture content was not significantly affected even though the vacuum went from -60 kPa to -54 kPa. This apparently contradictory result can be explained by the fact that two mechanisms that influence moisture content were affected at the same time. First, the drop in vacuum decreased the driving force for dewatering. Second, the residence time on the filter

cloth increased as the level in the tray decreased, which enhanced dewatering. The reason for the weaker vacuum was probably that a larger surface of the drum was exposed to air as the liquid level became lower. The greater access to air increased pressure equalization in the drum. Nevertheless, not diluting the lime-mud slurry before its uptake on the filter appears to have had a positive effect on the dry lime-mud feed rate to the kiln. This had a positive effect on feed-end temperature stability because the influx of lime mud varied less. The water flow for level control was measured as between 12.5 and 14.5 litres/s. The conclusion of the trial was that the level control does not appear to be necessary and could be shut off to stabilize the dry-mud feed rate and also make it easier to maintain high green liquor strength while also saving water.

Trial 2

As shown in Fig. 6, the washing of the doctor blade induces instability in the dry lime-mud feed rate. Therefore, in the second trial, the washing sequence was shut off. This was achieved by covering the back side (as well as the top side) in a non-stick material. When the washing was shut off, the induced spikes disappeared.

CONCLUSIONS

A new procedure for calculating the production of available CaO was developed. This calculation requires the mass flow, moisture content, and carbon content of the lime mud after the lime-mud filter together with the carbon content of the reburned lime. During implementation of this new calculation method, previously unnoticed process variabilities were discovered. Unexpected fluctuations in lime-mud feed rate and moisture content were observed. These fluctuations were revealed as minor feed-end temperature variations in the lime kiln. The temperature variations induced were generally too small to pose any major problems for maintaining satisfactory stability in a kiln equipped with a flash dryer. Furthermore, when using the new procedure for
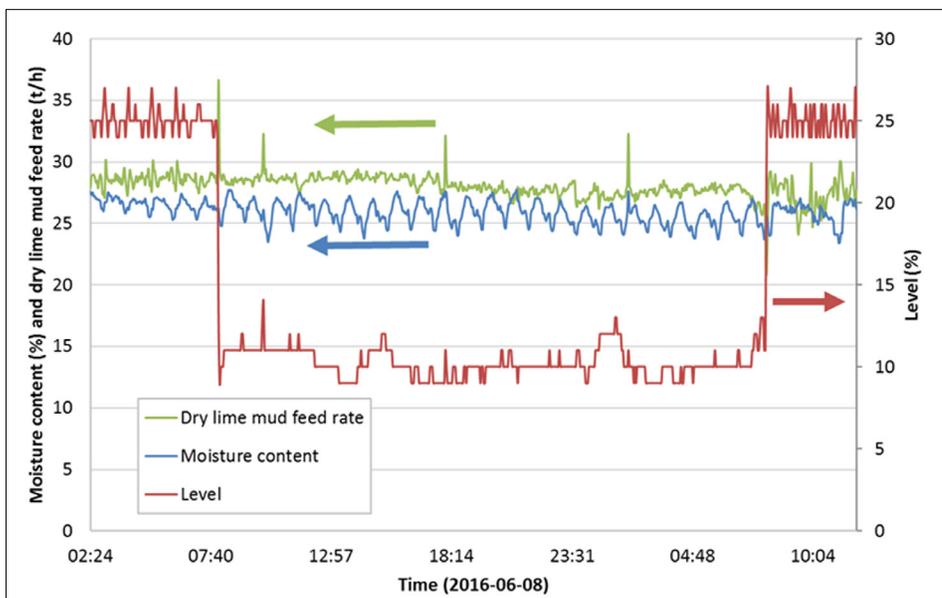

Fig. 7 - Dynamics of trial 1. The fuel supply and lime-mud feed rate after the filter were constant (32.3 MW and 38.8 tons/hour). The vacuum went from -60 kPa to -54 kPa. The distinct spikes in the dry lime-mud feed rate were caused by the doctor-blade washing sequence.

calculating reburned lime production, short periods with a large production increase were noticed when the doctor blade was washed, which led to lime mud falling directly into the kiln instead of being carried to the flash dryer. This introduction of moist mud into the kiln caused a distinct pulsation in feed-end temperature. Doctor-blade washing was then shut down to promote kiln stability. This was achieved by dressing the doctor blade in a non-stick coating. The lime-mud filter level control could also be shut off. These measures were beneficial for saving water and promoting stability in green liquor TTA and dry lime-mud feed rate and subsequently in lime-kiln feed-end temperature.

The proposed calculation procedure also proved to be a practical tool for predicting available CaO, which is helpful to avoid overliming.

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REFERENCES

1. Rydin, S., Haglund, P., and Mattson, E., "Causticizing of Technical Green Liquors with Various Lime Qualities," Svensk Papperstidning, 80(2): 54-58 (1977).

2. Hanson, C. and Theliander, H., "Properties and Quality of Lime, Part 1. The Influence of Conditions during Reburning", Nordic Pulp and Paper Research Journal, 9(3):161-166 (1994).

3. Tran, H., Mao, X., and Barham, D., "Mechanisms of Ring Formation in Lime Kilns", Journal of Pulp and Paper Science, 19(4): J167-J174 (1993).

4. Eriksson, G. and Theliander, H., "Displacement Washing of Lime Mud", Nordic Pulp and Paper Research Journal, 9(1): 60-66 (1994).

5. Lindblom, J., Wildt, J., and Theliander, H., "Sintering of Calcined Lime Mud: The Influence of Sodium and Sulphate Content in the Lime", Nordic Pulp and Paper Research Journal, 19(11): 23-30 (1998).

6. Wallbäcks, L., Theliander, H., Johanzon, O., Pettersson, T., and Welin, A., "Stable Lime Kiln Feed through On-Line Measurements and Feed Control", Proceedings, International Chemical Recovery Conference, Session 2B, 170-186 (2014).

7. Theliander, H., "On the Equilibrium of the Causticizing Reaction", Nordic Pulp and Paper Research Journal, 7(2): 81-87 (1992).