

ON-LINE DETERMINATION OF GREEN-LIQUOR REDUCTION EFFICIENCY AND TOTAL TITRATABLE ALKALI USING FOURIER-TRANSFORM-NIR SPECTROMETRY



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ABSTRACT

In this paper, we describe the use of Fourier-transform Near-Infrared spectrometry (FT-NIR) for on-line measurement of green liquor compositions, such as TTA, EA, carbonate, sulphide, sulphate, thiosulphate, and reduction efficiency (RE) in raw green liquor. The technical feasibility of using this analyzer as an on-line monitoring system for dissolving tank TTA control as well as for reduction efficiency monitoring has been demonstrated during normal mill operation as well as for simulated upset conditions. FT-NIR data for TTA has tracked well with dissolver density values. In addition, FT-NIR reduction-efficiency data has been correlated to changes in black-liquor solids content, primary air flow and black-liquor firing rate. Online TTA control could help stabilize TTA which will stabilize recaust operations. The ability to monitor reduction efficiency online will provide operators with better understanding of boiler conditions that lead to “poor” conditions with high TRS and dead-load.

KEYWORDS: Green Liquor, FT-NIR, TTA, Reduction Efficiency, Sulphate, Thiosulphate, Online Monitoring, TTA Control, Smelt Dissolving Tank, Recovery Boiler Optimization, Liquor Compositions

INTRODUCTION

The roles of the chemical recovery in kraft pulping are three fold: 1) process the organics and inorganic composition of black liquor, 2) generate steam and power for mill operations, and 3) recover chemicals (sodium and sulphur) and convert inactive to active chemicals for used in the digestion process. Highly efficient chemical recovery process is vital to the economic viability of kraft mills. As such, it can be referred to as the heart and soul of the operation and optimization of the recovery process is vital.

Optimization of the recovery boiler and hence the liquor cycle in a kraft mill remains a difficult challenge, even for a relatively modern mill, because of the lack of reliable on-line sensors capable of rapidly measuring the concentration of important green liquor components such as TTA (total titratable alkali), EA (effective alkali), sodium carbonate (Na_2CO_3), sodium sulphide (Na_2S), thiosulphate ($\text{S}_2\text{O}_3^{2-}$) and sulphate (SO_4^{2-}).

Accurate dissolving tank TTA, measured on a more frequent basis, could allow mills to reduce variability and set optimal TTA target. High TTA variability negatively impacts operational costs of the recovery process. Large swings in TTA could induce issues associated with weak white liquor to overliming scenarios at the slaker.

Since green liquor density is related to TTA, density measurement has been the technique of choice for smelt dissolving tank control. Typically, mill personnel perform TTA measurements or density measurements, such as a Baume, once every two to four hours. On-line density (bubble pipes, refractometers, and nuclear) measurements are common in most modern mills. However, density measurements are affected by other

ions present in raw green liquor (chloride, sulphate, thiosulphate, etc.) and are prone to drifts associated with scaling. Often, mill would report that the density meter from two separate green liquor lines do not match each other. In addition, small changes in density often lead to large change in TTA.

Percent reduction efficiency (%RE) is a direct indication of the efficiency at which the recovery boiler recovers the chemicals. Low reduction efficiency can be caused either by boiler operating conditions resulting in an oxidizing environment on the bed or the infiltration of air into the smelt spouts, the dissolving tank, or other components of the green liquor processing system. Manual testing for RE is time consuming, often RE analyses are done weekly or monthly. Good reduction efficiency for a modern mill will be around 98% with most mills averaging 95% while poorly operating mills see upper 80s. The lack of timely information does not lend well to optimization.

In general, poor reduction efficiency results in higher deadload content (Na_2SO_4) in green liquor. Increased deadload content may cause a greater incidence of scaling (burkeite) in the evaporator system and more frequent evaporator washes. With poorly optimized boiler operations, most mills must perform evaporator or concentrator washes every two to three weeks, with about six hours of downtime per wash, resulting in loss of production amounting to as much as \$240K per 6hr down time for a 1000 tonne per day mill.

In this paper, we demonstrate the applicability of an online analyser, based on Fourier-transform Near Infrared (FT-NIR) technology, for continuously monitoring raw green liquor compositions, including TTA, EA, AA, carbonate, sulphide, and sulphate, thiosulphate. In previous reports, we have

demonstrated the effectiveness and applicability of FT-NIR technology for measuring and monitoring other mill process streams [1], including that for digester applications (white liquor and black liquor compositions) and recausticizing operations (white and green liquor compositions). More details regarding the use of FT-NIR in the pulp and paper industry are provided in references [2-8].

MILL INSTALLATION

Hardware

An ABB Bomem FT-NIR spectrometer, NetworkIR, was used for all spectral data acquisition. ABB's FTSW100 software was used to interface with the spectrometer. All valve sequencing was controlled by the FTSW100 software. Data output was sent to mill DCS via OPC protocol. The flow-through cell is located out on the process floor, close to the sample tie-in point and is connected to the spectrometer via fibre-optic cables, up to 1000 feet away. Figure 1A illustrates a schematic installation with the spectrometer located in a MCC rack room with the flow cell installed out in the field. Figure 1B shows a mill installation photo showing the flow cell and sampling valves for dissolving tank liquor, equalization tank green liquor and weak wash.

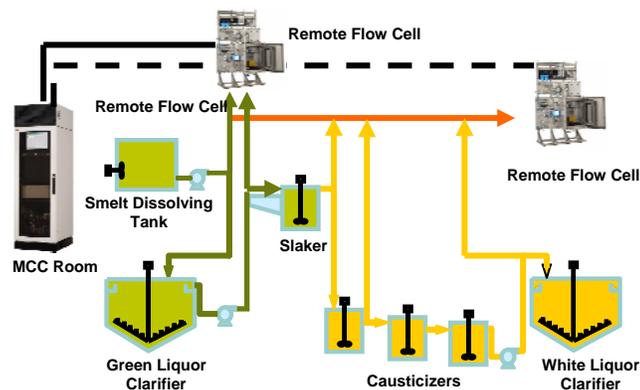


Figure 1A. Schematic illustration of the FT-NIR installation for smelt dissolving tank measurements.



Figure 1B. Actual installation at a Mill, showing valve installations for dissolving tank liquors, equalization tank liquors, and weak wash.

A sample tree is utilized to bring samples to the flow-through cell and each sample is sequenced according to a schedule or as a request from the DCS or an operator. Figure 2 illustrates a typical sampling tree and valving configuration for three streams. Upon a sample trigger, a specific green liquor or weak wash sample is allowed to flow to by-pass and then through the cell. Temperature, flow measurements, pressure, and conductivity readings are used to determine for the presence of fresh sample in the cell. When scanning of the sample is complete, reference water is used for flushing the flow-through cell while high pressure water is used to flush the sample back to the tie-in point. As such, only water is present in sample lines during idle periods. If any permissive is not met, such as boiler feed water pressure, a sample will not start.

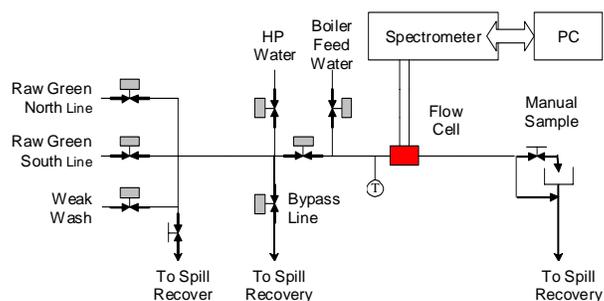


Figure 2. Typical sample line installation and valve hook up. Multiple samples can be tied into a sample tree and sequenced for sequential analyses with one flow cell. Each spectrometer can accommodate up to eight flow cells.

RESULTS AND DISCUSSION

Smelt Analysis

To determine which oxidized species exist predominantly in the smelt and whether the molten smelt or the unclarified green liquor represented the best sampling location for measuring reduction efficiency, we conducted a series of analyses with smelt samples taken from primary air ports and the spout, prior to smelt dissolution in the smelt dissolving tank. Samples were taken with a special sampling cup which allowed for minimal sample oxidation. Once sampled, the cup is sealed and allowed to cool. Analyses involved cutting of the solidified smelt and remove any region showing signs of oxidation. A known quantity is then dissolved in de-aerated deionized and distilled water to prevent oxidation. Measurements were performed with a FT-NIR, configure for manual sample entry, as well as standard high performance liquor chromatography (HPLC) and or ion chromatography (IC).

The smelt samples at Mill B were taken from the NW (Northwest) (#1) spout, the NW Primary Air Port and the SE Primary Air Port. The results of the analysis are shown in Table I. When comparing the samples, the smelt at the spout shows relatively low levels of sulphate and thiosulphate with a RE greater than 90% whereas the smelt taken from the two primary air ports has been oxidized by the oxygen present in the air and contains five to six times more sulphate and two to three times more thiosulphate. Also, sulphate levels are generally eight to ten times greater than thiosulphate levels on smelt samples taken through the primary air ports and four times higher than in samples taken from the smelt spouts. These results thus show that sulphate is the predominant oxidized sulphur species in the smelt. The reduction efficiency for samples collected through the primary air ports was only around 50%. It is understood and expected that the presence of oxygen at the primary air port level has a much greater impact on sulphate levels than on thiosulphate levels; however, thiosulphate was shown to be present in the smelt.

TABLE I
Smelt Analysis Results from Mill B

Location/Sample ID	[Na ₂ S ₂ O ₃] (%)	[Na ₂ SO ₄] (%)	[Na ₂ S] (%)	Reduction Efficiency (%)
NW Spout (No. 1)	0.35	1.49	20.8	93.3
NW Primary Air Port	1.19	7.34	10.3	58.4
SE Primary Air Port	0.70	8.82	9.8	52.6

Smelt samples were also collected from all four spouts at Mill B. The results of those analyses are shown in Table II. The reduction efficiency ranges from about 85% to more than 95% and appears to be influenced by variations in boiler operating conditions and by conditions at the localized environments around each spout. The concentrations of sulphate were consistently about ten times higher than thiosulphate for the smelt samples at Mill B, again showing that smelt RE is influenced more strongly by sulphate concentrations.

TABLE II
Smelt Analysis Results from Mill B

Location/Sample ID	[Na ₂ S ₂ O ₃] (%)	[Na ₂ SO ₄] (%)	[Na ₂ S] (%)	Reduction Efficiency (%)
No. 1 Spout	0.07	0.1	15.7	99.0
No. 2 Spout	0.22	2.2	18.0	88.9
No. 3 Spout	0.02	1.0	19.2	95.0
No. 4 Spout	0.26	2.6	17.0	85.6

Smelt samples from three different spouts at Mill C were also analysed. As seen from the top of Table III, the reduction efficiency for the three spouts were found to be in the same range as at Mill B, with typically very

low thiosulphate and sulphate levels. Similar smelt analyses for samples taken from the recovery boiler at Mill D are shown in Table IV. At Mill D, the variability from spout to spout was less than that seen in Mills B and C. The results of the smelt analysis at Mill C were then compared with those obtained with the raw green liquor taken directly from the smelt dissolving tank. (see Table III). It is immediately apparent that the thiosulphate level is higher in green liquor than the smelt and is comparable to those of sulphate in the green liquor. This is not surprising since the weak wash consists of partially oxidised white liquor, in which the main constituents are sodium thiosulphate and sodium hydroxide.

TABLE III
Smelt Analysis Results from Mill C

Location/Sample ID	[Na ₂ S ₂ O ₃] g/L Na ₂ O	[Na ₂ SO ₄] g/L Na ₂ O	[Na ₂ S] g/L Na ₂ O	Reduction Efficiency (%)
No. 4 Spout (%)	0.34	0.43	22.9	96.7
No. 5 Spout (%)	0.03	0.43	22.0	97.9
No. 6 Spout (%)	0.32	1.95	17.7	88.6
Raw green liquor(g/L Na ₂ O)	1.45	2.15	35.1	90.7

TABLE IV
Smelt Analysis Results from Mill D

Location/Sample ID	[Na ₂ S ₂ O ₃] (g/L Na ₂ O)	[Na ₂ SO ₄] (g/L Na ₂ O)	[Na ₂ S] (g/L Na ₂ O)	Reduction Efficiency (%)
NW	0.25	1.16	14.4	91.1
SW	0.22	1.68	14.5	88.4
NE	0.20	1.44	16.6	91.0
SE	0.16	1.10	14.8	92.1

These results suggest that the monitoring of dissolving tank green liquor should include thiosulphate as it is a deadload component. These findings suggest that reduction efficiency may need further differentiation; smelt reduction efficiency and green liquor reduction efficiency whereby thiosulphate should be included in green liquor reduction efficiency calculation. Further more, the data from the smelt analysis confirms that sulphate mainly originates from the boiler (not from weak wash) and that variations in reduction efficiency, which ranges from the mid-80s to high-90s, occur from spout to spout because of localized fluctuations in boiler performance and/or air entrainment around the spout.

In addition to the spout-to-spout variability, technical difficulties associated with smelt analysis make it infrequent and analyses performed directly on smelt would not be available in sufficient frequency to correlate with process variables. Since sulphate levels obtained from smelt analysis is similar to that provided by the in raw green liquor, it can be concluded that the smelt dissolving tank is the best sampling location for monitoring sulphide and sulphate levels and characterising boiler operations, especially since the smelt dissolving tank can be sampled continuously.

Table V compares the FT-NIR results obtained for green liquor sulphate and thiosulphate with those of standard technique for measurements. The results clearly indicate that FT-NIR spectrometry can be utilized for dissolving tank green liquor composition analyses, including complete ABC compositions and sulphate and thiosulphate concentrations. The root mean squared standard error of prediction (RMSEP) was determined to be ± 0.2 and ± 0.6 g/L as Na_2O for thiosulphate and sulphate, respectively. TTA, carbonate, and sulphide can be measured with accuracies of ± 0.8 g/L.

TABLE V
Validation of Raw Green Liquor Sample Analyses from Mill A

Sample ID	$[\text{Na}_2\text{S}_2\text{O}_3]$ (g/L Na_2O)		$[\text{Na}_2\text{SO}_4]$ (g/L Na_2O)	
	FT-NIR	Commercial Laboratory	FT-NIR	Commercial Laboratory
A	1.4	1.4	4.1	4.5
B	1.5	1.5	5.5	6.5
C	1.6	1.4	8.1	8.5
D	1.5	1.4	8.8	8.8

TABLE VI
Validation of Raw Green Liquor Sample Analyses from Mill D

Sample ID	TTA g/L Na_2O		$[\text{Na}_2\text{CO}_3]$ g/L Na_2O		Na_2S g/L Na_2O	
	FT-NIR	Titration	FT-NIR	Titration	FT-NIR	Titration
A	119.7	120.4	73.8	74.4	26.2	26.4
B	118.8	121.9	71.9	75.6	25.6	27.0
C	115.3	114.4	69.6	69.6	25.2	25.0
D	114.8	115.4	70.2	69.8	25.2	25.1
E	115.4	114.7	70.3	69.9	25.1	24.8
F	118.0	115.3	69.5	72.4	24.8	25.7

Online Smelt Dissolving Tank Green Liquor Measurements

The mill installation saw that the FT-NIR spectrometer was mounted in a 19" rack mounted industrial cabinet along with the computer and CanOpen communications device. The flow cell, solenoids, and other electronics are assembled on a sampling skid which is mounted on the process floor. The mill provided sample tie-in lines and isolating valves. All lines are $\frac{1}{2}$ " SS316 ball valves with pneumatic actuators. Raw green liquor tie-in points were from both transfer lines and merged to a common line leading to the sampling station at the FT-NIR Liquor analyser. Stabilization tank outlet GL and weak wash were also analysed.

Figures 3 – 5 compares FT-NIR results (TTA, carbonate, sulphide) and density from for raw GL. It is evident that the FT-NIR TTA values matched that of the density swings.

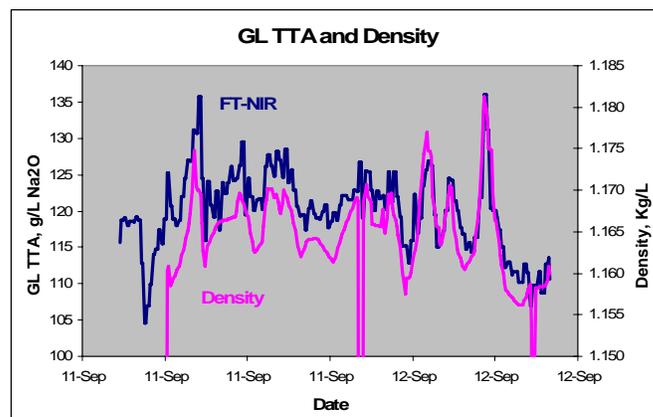


Figure 3. Dissolving tank FT-NIR TTA and dissolver density. The FT-NIR TTA is shown to correlate well with the density for this period.

As seen above, there is much variability with this mill's dissolving tank TTA. The TTA ranges from 105 g/L (as Na_2O) to 135 g/L for this period. Though there are various occasions that the density measurements seem to drop out, the FT-NIR continues to provide accurate TTA values.

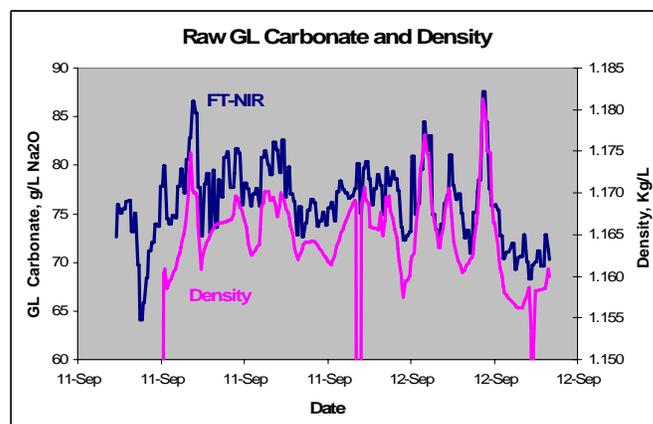


Figure 5. FT-NIR GL carbonate plotted with green liquor density.

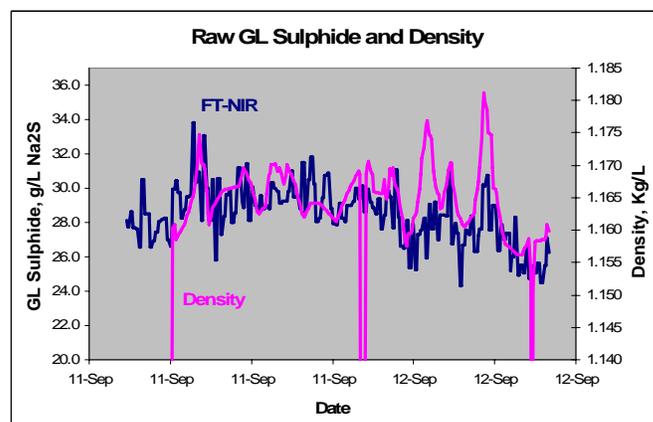


Figure 6. FT-NIR GL Sulphide concentrations with dissolver density.

Comparing Figures 3 – 6, one sees that the major contribution to GL TTA is carbonate followed by sulphide. Dissolving tank GL EA was not found to be a major contributor to TTA variability as the caustic portion of the GL is primarily from the weak wash. There seems to be greater correlation between sulphide and TTA than between carbonate and TTA. However, carbonate has a larger weight portion of the total TTA and as much as 2/3 of TTA variability is due to swings in carbonate variability. As such, when TTA swings, carbonate and sulphide swings with TTA while the EA remains relatively constant. The FT-NIR TTA provides more accurate and higher resolutions required for process optimization opportunities.

Figure 6 below shows periods whereby the FT-NIR and the dissolver density do not agree. The mill switches the transfer lines every few days, between transfer line A and B.

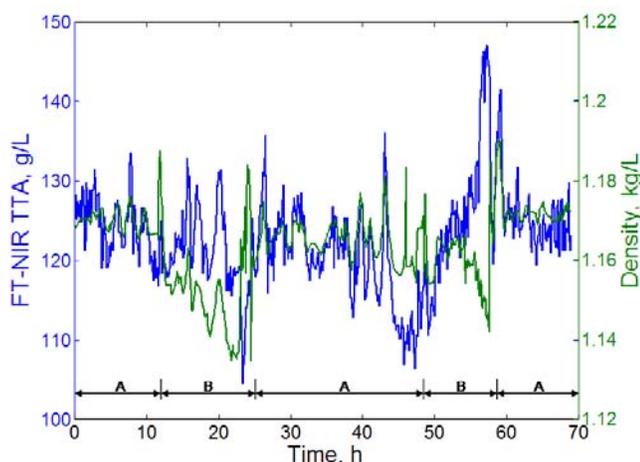


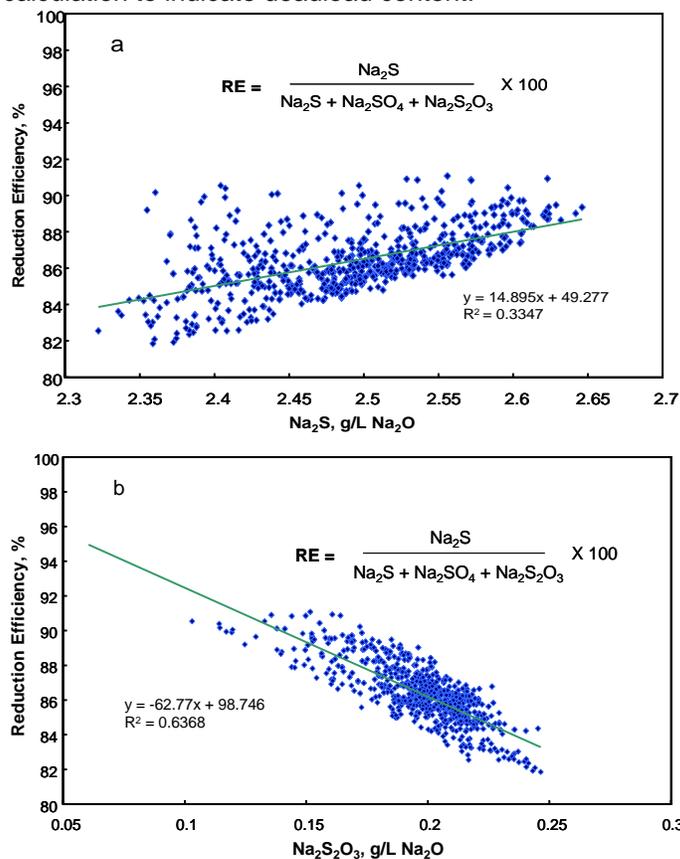
Figure 6. Comparing FT-NIR TTA (blue) results with dissolver density (green) meters. Period A and B refer to density meter readings on A and B transfer lines.

Referring to Figure 6, the FT-NIR results correlated with the density for transfer line A and no correlation with density meter on transfer line B. As a matter of fact, the density on transfer line B actually diverges with the true FT-NIR TTA measurements. This example shows the difficulty that mills face when running with density measurements. Due to scaling of the density meter, measurement drifts were often observed. When green liquor transfer lines are switched, often the density values do not match. These differences and operating issues could induce variability of the green liquor TTA. More frequent recalibration of the density meters was required to keep the two meters in agreement. The FT-NIR shows no sign of scaling, provided that HP clean water is available for backflushing and reference water is available for cell flushing.

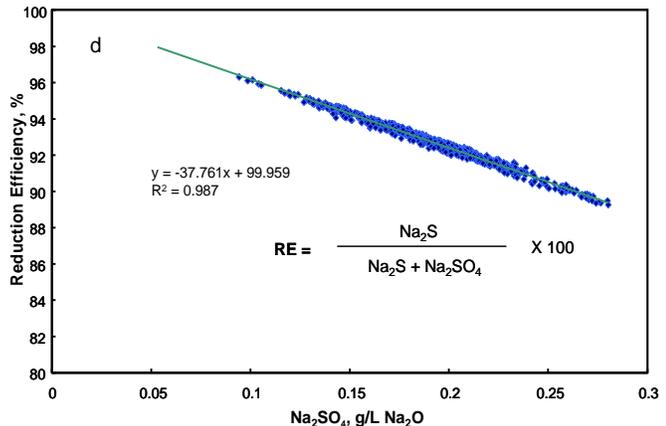
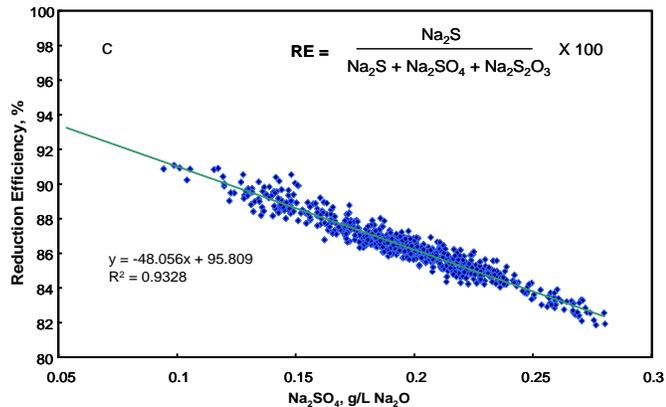
Online Smelt Dissolving Tank GL Reduction Efficiency

The FT-NIR spectrometer package was sent to a mill (Mill B) for installation at the #4 recovery boiler dissolving tank for raw green liquor measurements. This boiler is a Combustion Engineering boiler, 32 feet wide and 38 feet deep. It normally operates at 71-72% solids with a two-wall primary air set up. Measurements were set to provide results every fifteen minutes.

The relationship between RE and green-liquor sulphide, thiosulphate and sulphate is shown in Figures 7a-d, for data collected over a period of a month. The green liquor RE shown in Figure 7a-c was calculated by including the thiosulphate concentration, whereas the RE in Figure 7d did not. As expected, sodium sulphide increases with increasing RE while sulphate and thiosulphate decreases with increasing RE. A much stronger correlation is observed when sulphate alone is used for the RE calculation. Thiosulphate tends to be generated more with entrained air operations of the dissolving tank and with weak wash than that correlated to recovery boiler operation. While the intercept in Figure 7d is close to 100% as expected, the intercept in Figure 7c is about 96%, which indicates that a small but relatively constant amount of thiosulphate was entering the smelt dissolving tank with the weak wash during the monitoring period. Hence, the recovery boiler reduction efficiency is best calculated without including thiosulphate while green liquor reduction efficiency should include thiosulphate concentration in the calculation to indicate deadload content.

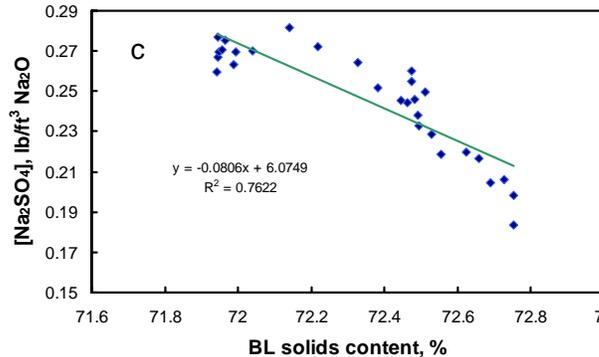
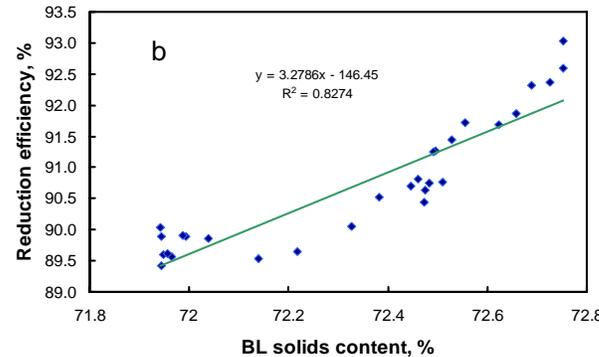
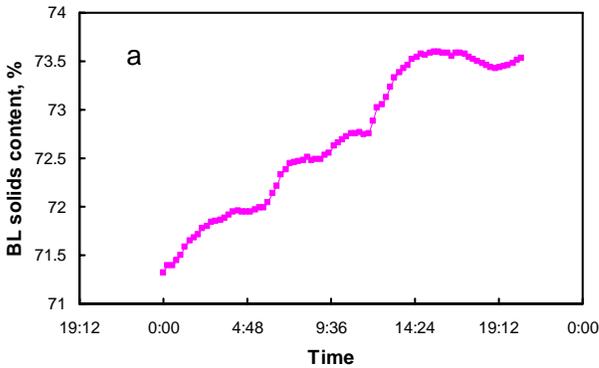


primary air flow, more efficient chemical recovery was obtained, to be accompanied by hotter char bed and lower furnace, which leads to increases in the reduction efficiency. These results will be boiler specific.



Figures 7a-d. Relationship between green liquor reduction efficiencies variations with chemical compositions: (a) sulphide, (b) thiosulphate, (c) sulphate with RE calculation including thio and (d) sulphate with RE calculation not including thio.

To get a better understanding of the various operating parameters that most affect RE, process data for individual and combined parameters were further studied to observe correlation with the calculated RE. Figure 8a shows a period with increasing black liquor solids while Figures 8b-d show the effect of increasing black-liquor solids content on the reduction efficiency (8b), the green-liquor sulphate (8c) and the green-liquor sulphide (8d), for this particular boiler. As the solids content is increased, the sulphate concentration drops while the sulphide concentration rises. The linear correlation is shown only to illustrate change in concentration and does not imply a linear kinetic order, although it can be argued that, after the first period, the change is quite linear. At first glance, the process data show that the increase in black-liquor solids content, from 71.8% to 73%, is highly correlated with an increase in percent RE, from 89 to 93%. However, in response to an increase in solids content, the operator raised the primary air, and perhaps the total air flow, in anticipation of higher boiler loading to prevent starving the boiler while maintaining combustion efficiency. Over the same time period, the primary air was increased from 265 to 295 Klbs./hr. These results show that, with higher solids content and an increase in



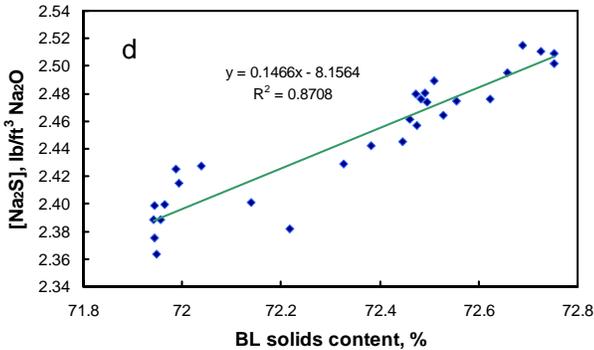


Figure 8a-d. Process parameters showing period of operation whereby changes in BL solids (and primary air changes) led to an increase reduction efficiency.

Figure 9 shows a contour plot relating the effects of both primary air flow and black liquor solids to reduction efficiency. The RE data is fitted with a distance weighted least squares algorithm (Origin software). This contour plot shows that, for this specific boiler, if one were to fire black liquor with a solids content of 69%, a primary-air flow of around 320 Klbs/hr. (top left corner) would maximize RE. As black-liquor solids increase (69% to 75%), and assuming no increase in the actual firing rate, one would move diagonally downwards, gradually reducing the primary air flow to approximately 220 Klbs/hr, maintain high RE. Overall, one would change the air-splits by shifting primary air to secondary and tertiary air. This operating strategy is in agreement with our current knowledge.

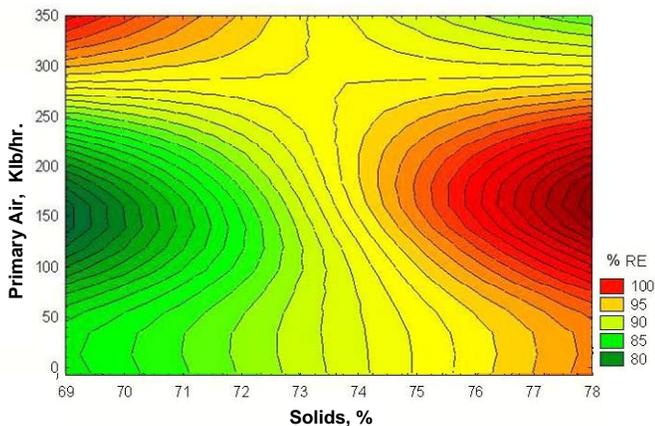


Figure 12. Contour plot relating primary air flow with black liquor solids content to green liquor reduction efficiency. Red indicates higher reduction efficiency.

Boiler optimization trials: Air balancing and liquor firing system adjustments

To demonstrate the feasibility of using the analyser results to guide boiler optimization, we then proceeded to optimize Mill B's #4 boiler operations, first by properly balancing the air system, adjusting the air splits and then by increasing the liquor firing rate, from

3.4 to 4.5 Mlbs of dry BLS/day while keeping the same air-to-fuel ratio (or a constant O_2 at boiler exit). The objective of the air system optimization was to determine whether this particular boiler was able to handle higher liquor firing rates and to identify any deficiencies. We also performed carryover tests throughout the trials to verify the practicality of running the boiler at higher firing rates. Carryover was measured on the 10th floor, 30 feet above the bullnose.

The baseline data (Table VI) collected on the first day of the trial indicated that the average bed temperature was 939 °C while the RE was 88.8%. 9.8g of carryover were collected on a 1-inch diameter by 6-inch long pipe nipple in a 10-minute exposure using a simple deposit probe [28-10], at a firing rate of 3.4 Mlbs black liquor solids (BLS) per day. As we increased the firing rate, at the same fired solids concentration (71.7%), the RE value increased along with the bed temperature and carryover. With the carryover climbing close to a recommended upper limit, boundary condition measurements on the air system was carried which showed that there was a burner port that was leaking and skewing the air flow pattern. After shutting off the burner port and rebalancing the air, Test-1 on the following day showed higher RE as well as a dramatic drop in the carryover (from 11.5 to 7.5 g/10-minute exposure). When the boiler load was then further increased to 4.5 Mlbs BLS/day, the RE value increased along with the bed temperature while the measured levels of carryover stayed low. In this air system optimization process, we see that the reduction efficiency increased from 88.8 to 93.4%, the char bed temperature increased from 939 to 1008 °C, the stack oxygen dropped from 4.0 to 1.3% (due to better gas mixing), and steam generation increased from 3.4 to 3.8 lb/lb fired BLS. Because of a power limitation on the ID fan, tests could not be carried out at higher firing rates.

Table VI Results from the boiler-optimization trials at Mill B					
Parameters	Units	Feb24	Feb25	Feb26 Test 1	Feb26 Test 2
BL firing rate	Mlbs BLS/ day	3.4	4.0	4.0	4.5
Average % RE	%	88.8	90.6	92.5	93.4
Stack O_2	ppm	3.2	1.2	1.4	1.3
Carryover	g/10 min.	9.8	11.5	7.5	8.3
Bed temperature	°C	939	985	980	1008
BL Solids content	%	71.7	71.7	71.7	72.0

ACKNOWLEDGEMENTS

Data from the results obtained from the mill trials have more than shown that FT-NIR Liquor Analyser is capable of provide accurate green liquor compositions, including TTA, EA, carbonate, sulphide, as well as sulphate and thiosulphate. Dissolving tank green liquor TTA correlated well with dissolver density. FT-NIR green liquor analyser provided more accurate TTA results and more suited for green liquor compositional analyses with less maintenance as compared to density measurements. From our trials, we have begun work to utilized FT-NIR green liquor analyser to develop smelt dissolving tank control strategy. The objective is to minimize TTA variations and select the best operating targets with maximum economic benefits in mind.

Further data analyses and understanding of sulphate and thiosulphate concentrations and their impact on reduction efficiency, boiler performance, and effects on the liquor cycle will lead to better appreciation of boiler liquor chemistry. As there are other variables that also affect reduction efficiencies, control strategies for recovery boiler will be more difficult to develop but will be looked at. These measurements allow for better understanding and opportunities to optimize boiler liquor chemistry and their effects on mill wide costs.

CONCLUDING REMARKS

Fourier-transform Near-Infrared spectrometry has been successfully applied to the measurement of smelt dissolving tank green liquor compositions, including that of TTA, EA, carbonate, sulphide, as well as sulphate and thiosulphate. On a lab scale, the FT-NIR can be used as a benchtop device while online measurements can be coupled with a transmission cell. Sulphate concentrations dominated the oxidized smelt, as sampled from primary and secondary air ports. We have shown that smelt reduction efficiency varies from spout to spout and, due to difficulty in sampling analyses, the results cannot be easily used for optimization of boiler operations.

Installations of FT-NIR technology, coupled to a flow-through cell, with automated sequencing, allowed more accurate and frequent analyses. Dissolving tank green liquor TTA showed excellent correlation with GL density and is an improvement on density measurement. GL reduction efficiency data was correlated to changes in black liquor solids content, primary air flow and black liquor firing rate. While these changes in reduction efficiency to boiler operation show excellent promise, more data is needed to understand effects of boiler chemistry on mill-wide implications.

Instrumentations, design and data handling was provided by Dave Pouw of FPIInnovations. We also wish to thank the personnel of the power/recovery departments at our Member mills during the course of the trial. Special thanks must also go to Bruce Halvorson and Kirstin Maki for their help in installing and troubleshooting the on-line reduction green liquor analyser.

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