NON-PROCESS ELEMENT MASS BALANCE IMPROVES RECAUST AND LIME KILN EFFICIENCY AT ELK FALLS MILL

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ABSTRACT

Filtered lime mud at the Elk Falls mill routinely had low solids content and a dark green color. It was estimated that low solids content and high dead load were resulting in additional lime kiln fuel costs of nearly $300,000/year. A detailed study of non-process elements (NPEs) present in the Elk Falls mill was implemented. Composite samples from fifteen different process streams were collected and analyzed for 24 different elements. Using the known flow rates of these process streams at the mill, a mass flow balance of NPEs was obtained. Together with historical data, this work provided a clear picture of NPE accumulation in the mill. Lime kiln fuel oil was found to be a significant source of phosphorus, iron and zinc. It was possible to establish NPE specifications for lime rock, fuel oil, salt cake, and clarified green liquor. Cost-effective process modifications increased lime mud solids content and reduced kiln dead load.

INTRODUCTION

This paper describes a non-process element (NPE) mass balance conducted at Elk Falls mill. This study was implemented to provide a clear picture of NPE accumulation in the Elk Falls lime cycle. NPE accumulation was suspected of causing low solids content in filtered lime mud and excessive kiln dead load. Incremental fuel costs from these two factors were estimated at nearly $300,000/year. The mass balance was necessary to determine the most cost-effective way to address the process problems, and to provide the data needed to establish NPE specifications for lime rock, fuel oil, salt cake and clarified green liquor.

The mass balance mill trial was designed based on a detailed understanding of the chemistry of the Elk Falls green liquor clarifier and lime cycle as reported by Taylor and McGuffie [1].

Located near Campbell River on the east coast of Vancouver Island, Elk Falls began operation in 1952 as a single-line newsprint mill. The paper machine was joined with a kraft pulp mill on the same site in 1956 and two other paper machines followed in 1957 and 1982. A kraft paper machine was installed in 1966. Sawdust pulp, a product pioneered at Elk Falls, was first manufactured in 1964 and capacity expanded in 1983. The Kraft mill was simplified in 2004, and is now a single-line operation. Elk falls currently produces about 830 t/d of Kraft and 1600 t/d of TMP.

The behaviour of NPEs in the kraft recovery cycle has been reviewed [2,3]. A number of papers have been published on the mill concentrations of NPEs in kraft process streams [4-10].

This paper examines a wider range of NPEs than previous mill studies and includes additional process streams important to the lime cycle, including weak wash, kiln fuel oil and dregs filtrate. Process changes made at the Elk Falls mill as a result of the mass balance are also discussed. Based on this work NPE specifications for lime rock, fuel oil and clarified green liquor were established for the Elk Falls mill.

METHODS AND MATERIALS

For each of the 15 process streams, three samples were collected over an eight hour period on August 25, 2005 and combined into one composite sample. Raw green liquor was a two sample composite because of a change that occurred in recovery boiler operation. Lime rock was a composite sample collected May 19/05. Pulp production that day was 565 ADT. Results are given in **Tables 9&10 (Appendix)**.

Samples for the mill trial were collected in polyethylene sample containers. Containers were first soaked in 1+1 HCl then rinsed in deionized water and dried before sampling, to eliminate possible metal contamination.

Elemental concentrations were measured by Econotech Services Ltd., Delta, BC. Samples were digested with aqua regia at 100°C for 2 hours. Some samples required alkali fusion with sodium carbonate and boric acid at 1000°C. After digestion, samples were analyzed by inductively coupled plasma (ICP) spectroscopy. Total element content was measured in liquid samples.

Flow rates of process streams were initially estimated using process instrumentation, then adjusted to balance sodium ion mass flow. Flow adjustments were made for white liquor (+10%), strong black liquor (-25%) and weak wash to dissolving tank (+33%). No other flow adjustments were made, and good balance of the sodium mass flow was obtained as seen in **Tables 1 & 2**.

RESULTS

1. Overview of Samples Collected for Mass Balance

Element concentrations of the collected samples are shown in **Table 9 (Appendix)** for samples that were solid or measured on a solids basis. Element concentrations in **Table 10 (Appendix)** are for liquid samples. There are several initial observations that can be made about the results in these two tables.

Weak and strong black liquor solids have the same sodium and potassium concentrations as expected, but NPE levels vary considerably between the two. Silicon, magnesium and calcium showed the largest differences. This shows that there is significant variability in the black liquor composition, probably due to changes in the wood used. This could be due to variability in NPE concentration in the wood itself, or to variability in contaminants like dirt, sand and iron.

Dregs and slaker grits required alkali fusion to completely dissolve the elements aluminum, calcium, iron, magnesium, manganese and silicon. These elements were present in compounds that were not soluble in hot nitric acid, most likely as silicate or aluminosilicate compounds [1,11].

The fuel oil used for the lime kiln contained high concentrations of phosphorus, zinc and iron. Fuel oil made a significant contribution to these NPEs in the recaust area and this is discussed in detail below.

Salt cake used at Elk Falls was of high purity and had insignificant NPE levels.

2. Mass Flow Overview

The results in **Tables 9&10 (Appendix)** were converted to mass flow rates of each NPE in units of grams/minute. This allows direct comparison of the different process streams. Process flow rates used in the calculations are also given in the tables. The sodium and potassium mass flows are included in **Tables 1 & 2** to show that their mass balance is consistent.

White Liquor to Black Liquor to Raw Green Liquor

The mass flows of NPEs present in white liquor are shown in **Table 1**. The change in NPE mass flows from white liquor to black liquor represent the net gain or loss of NPEs during the pulping process. Variations in mass flow of NPEs in the weak and strong black liquor show that there is significant process variability. Notice that silicon mass flow drops significantly from white liquor to black liquor. This is due to loss of silicon to the pulp [4,12]. This is a well-known process and is the major loss of silicon at Elk Falls. However, a large quantity of silicon is recirculated with the weak wash. Aluminum is gained during the pulping process, mostly from aluminum in the wood itself, and also from clay contamination in the sawdust. Iron increases significantly during pulping, due to iron in the wood and to metallic iron and rust that contaminate the sawdust. Phosphorus, calcium and magnesium all increase significantly, due to their presence in the wood itself. Salt cake addition was not included in the table since its effect on NPE and sodium mass flow at Elk Falls is negligible. Calcium mass flow in the raw green liquor was significantly lower than in the black liquors. This may be due to process variation or to precipitation of calcium compounds in the black liquor system. NPE mass flow in the raw green liquor is roughly the sum of black liquor and weak wash mass flows.

Aluminum, silicon, iron, phosphorus, zinc and magnesium will be discussed individually in the next section of this paper.

Table 1. NPE Mass Flow, White Liquor to Raw Green Liquor

Mass Flow, g/min	White Liquor	Weak Black Liquor	Strong Black Liquor	Weak Wash	Raw Green Liquor
Al	58.4	64.9	77.7	12.2	93.5
Si	572	423	388	154	694
Fe	8.1	110	121	0.8	123
P	14.9	51.9	64.0	1.9	61.5
Ca	19.8	242	402.4	6.0	165
Mg	1.4	135	218.6	0.0	157
Ba	0.6	2.2	3.3	0.1	2.7
Mn	8.7	71.3	84.0	0.2	75.8
V	8.4	7.8	7.5	2.3	9.8
K	7,088	6,726	6,858	1,762	8,758
Na	193,644	181,776	191,117	47,040	233,454
Flow rate, L/s	33	86.5	21	40	41

Green Liquor Clarifier

Mass flow rates of NPEs from raw green liquor to clarified green liquor are shown in **Table 2**. The green liquor clarifier is the most important removal point for iron, manganese and zinc in the Elk Falls mill. The clarifier is also the most important removal point for aluminum, even though removal efficiency is low. Note that 99% of magnesium ion is removed from the raw green liquor as it flows through the clarifier. No phosphorus is removed in the clarifier.

Table 2. NPE Mass Flow, Raw Green Liquor to Clarified Green Liquor

Mass Flow, g/min	Raw Green Liquor	Dregs	Dregs Filtrate	Clarified Green Liquor	Percent Removal
Al	93.5	27.6	0.1	73.8	21
Si	694	69.8	3.8	694	<10
Fe	123	142.6	0.1	13.0	89
P	61.5	1.0	2.5	64.0	0
Ca	165	279	11.6	24.6	85
Mg	157	163	0.1	1.1	99
Ba	2.7	0.8	0.0	2.4	11
Mn	75.8	80.1	0.0	10.3	86
Ti	1.4	1.7	0.0	0.2	86
V	9.8	0.2	0.1	10.4	0
Zn	4.2	4.2	0.0	< 0.5	99
K	8,758	156	96	9,323	-
Na	233,454	3,592	2,589	248,460	-
Flow rate, L/s	41		0.94	41	
Flow rate, kg/min		65			

During dregs filtration, both sodium and potassium compounds are lost as carbonates to the dregs (**Table 10, Appendix**). Aluminum concentration is also reduced significantly during dregs filtration, most likely to the cooling of the filtrate and a decrease in aluminum solubility [13].

Table 3. NPE Mass Flow, Recaust

Mass Flow, g/min	Lime Mud	Grits	Lime Rock	Fuel Oil	Kiln Precip Catch	Precip. Catch to Sewer
Al	164	2.3	0.2	0.7	30.9	1.8
Si	390	6.1	2.0	0.9	86.1	5.1
Fe	430	5.6	0.4	2.9	81.9	4.8
P	1,684	16.2	0.1	16.5	362	21.3
Mg	628	7.1	2.6	0.7	115	6.7
Ba	51.7	0.5	0.0	0.5	10.4	0.6
Sr	174	1.8	1.1	0.0	34.9	2.1
Mn	49.2	0.4	0.0	0.1	9.1	0.5
Ti	5.1	0.05	0.0	0.0	1.1	0.1
V	3.7	0.04	0.0	0.6	1.3	0.1
Zn	296	2.6	0.0	22.2	69.7	4.1
Flow, kg/min	282	2.9	1.3	29.4	42	3.1

Recaust Area

Table 3 shows the NPE mass flow rates in the recaust area. Mass flow rates of elements in lime mud and lime were slightly different due to errors in measuring flow rate and moisture content. In addition, the mass flow rates of several NPEs are high in lime mud and lime because they accumulate in the lime cycle. Fuel oil shows significant mass flow of iron, phosphorus, and zinc.

3. Mass Flow Rates of Individual NPEs

From previous work in this project [1], the non-process elements important to the Elk Falls mill have been identified as aluminum, silicon, iron and phosphorus. Aluminum and silicon are most important in the formation of aluminosilicate compounds and can reduce the solids content of lime mud to the kiln. Iron may contribute to the formation of these compounds. All NPEs contribute to kiln dead load, but phosphorus is the largest contributor, tying up at least five times its weight in calcium phosphate compounds. Zinc is included in the discussion below because it has been identified as another dead load component at Elk Falls.

Aluminum

From **Table 4**, essentially all of the aluminum entering the recaust area of the Elk Falls mill arrives in the clarified green liquor. Aluminum exits the recaust primarily with the white liquor (78%). About 16% of the aluminum mass flow in the recaust area is recirculated in the weak wash. Aluminum losses through slaker grits and sewer are near 5% of the total flow. From **Table 4**, input and output of aluminum in the recaust area is balanced at about 75 g/minute. This compares to the mass flow of aluminum in lime of about 150 g/minute.

Table 4. Aluminum Balance – Clarified Green Liquor to Weak Wash

	Flow Units	Flow Value	Al, ppm	Al, g/min	% of total
Inputs:					
Clarified Green Liquor	L/min	2,460	30	73.8	98.8%
Lime Rock	kg/min	1.30	152	0.2	0.3%
Fuel Oil	L/min	30	23.4	0.7	0.9%
Total:				74.7	
Outputs:					
White Liquor	L/min	1,980	29.5	58.4	78.1%
Weak Wash	L/min	2,400	5.1	12.2	16.4%
Slaker Grits	kg/min	2.9	968	2.3	3.0%
Precip catch to sewer	kg/min	3.13	735	1.8	2.4%
Total:				74.7	
Lime	kg/min	120	1,270	152	

In the green liquor clarifier, a significant amount of aluminum mass flow (27%) is lost in the dregs. Green liquor clarifier dregs are the major purge point for aluminum at the Elk Falls mill. Aluminum-containing compounds in the dregs were identified by XRD as pargasite, $NaCa_2Mg_3Fe^{2+}Si_6Al_3O_{22}(OH)_2$, and vermiculite, $Mg_{1.8}Fe^{2+}_{0.9}Al_{4.3}SiO_{10}(OH)_2 \cdot 4(H_2O)$ by Taylor and McGuffie [1]. Both of these compounds contain magnesium, and it is likely that adding magnesium to the dissolving tank would result in reduced aluminum concentrations in the clarified green liquor.

Silicon

Silicon mass flows do not balance as well as the other NPEs examined. This is most likely because of the difficulty of accurately measuring silicon concentration in different process streams. However, the results obtained in the August 25/05 mill trial still provide some important conclusions.

The major purge point of silicon is with the pulp, as seen in **Table 1**. This behavior is well known [4,12]. Silicon mass flow decreases by approximately 30% from the white liquor to the black liquor. In Finnish kraft mills, silicon losses to unbleached pulp ranged from 40 to 400 g Si/BDt [12]. In comparison, estimated Elk Falls silicon losses to unbleached pulp are at the upper end of this range.

From **Table 5**, silicon mass flow is unchanged within experimental error as this element travels through the recaust area. Lime rock does contribute to silicon mass flow, but the percentage is very small at current rates of lime rock addition.

Table 5. Silicon Balance – Clarified Green Liquor to Weak Wash

	Flow Units	Flow Value	Si, ppm	Si, g/min	% of total
Inputs:					
Clarified Green Liquor	L/min	2,460	282	694	99.6%
Lime Rock	kg/min	1.30	1,530	2.0	0.3%
Fuel Oil	L/min	30	30.6	0.9	0.1%
Total:				697	
Outputs:					
White Liquor	L/min	1,980	289	572	77.6%
Weak Wash	L/min	2,400	64.2	154	20.9%
Slaker Grits	kg/min	2.9	2,570	6.1	0.8%
Precip catch to sewer	kg/min	3.13	2,050	5.1	0.7%
Total:				738	
Lime	kg/min	120	2,990	359	

A significant amount of silicon (21%) is recycled in the weak wash. Based on the dilution factors of white liquor, some silicon may be entering the weak wash with mill water/wash water. It is estimated that this amount could be up to 13 g/min, or less than 2% of the total mass flow. This amount was estimated based on the relative dilution of sodium, chloride and silicon from white liquor to weak wash. This would only require approximately 7 mg/L of silicon in the mill water used to wash the lime mud.

On a percentage basis, very little silicon is lost through slaker grits or to sewer. The mass flow of silicon through the recaust area is nearly double the mass flow of silicon in the lime. Silicon concentration in lime rock is slightly lower than silicon in the precipitator catch. As a result, increased lime rock addition will not have much effect on silicon concentration in the lime mud.

Approximately 9% of the mass flow of silicon appears to be lost to dregs in the green liquor clarifier. Primary silicon-containing compounds in the dregs were identified by Taylor and McGuffie [1] as diopside ($CaMgSi_2O_6$), pargasite and vermiculite. These compounds contain magnesium. Addition of magnesium to the dissolving tank could have the added benefit of removing additional silicon from the process cycle.

Iron

The green liquor clarifier was able to remove about 92% of the iron present in the raw green liquor and is an efficient removal point for iron at the Elk Falls mill. **Table 6** shows that the most important input of iron into the recaust area is the clarified green liquor. A small increase in iron content in the clarified green liquor will have a large effect on iron input to the lime cycle. The suspended solids content of the clarified green liquor is a good guide to iron content, since iron concentration is roughly proportional to the suspended solids content. **Table 6** shows that lime rock with 290 mg/kg iron content contributed only 2% to the iron input to the recaust area. A surprising source of iron to the recaust was the fuel oil. It contributed roughly 18% to the mass flow of iron, due to a high iron concentration of nearly 100 ppm. Iron concentration in the fuel oil should be as low as possible.

The most important loss of iron from recaust was the white liquor, at about 42% of the total. Iron concentration in white liquor is relatively constant, since this element is at its solubility limit [7]. Other important purges of iron from recaust are the grits (29%) and precipitator catch to sewer (25%). During the August 25/05 mill trial, it appears that the iron input into the recaust was less than output by about 3 g/minute. This is primarily because the green liquor clarifier was operating efficiently.

Mass flow of iron in the lime is 384 g/minute, much higher than the loss of iron seen during the mill trial. The amount of time required to reduce iron concentration in the lime and lime mud will depend on the total mass of iron in the system, and is discussed in the section on NPE inventory.

Table 6. Iron Balance – Clarified Green Liquor to Weak Wash

	Flow Units	Flow Value	Fe, ppm	Fe, g/min	% of total
Inputs:					
Clarified Green Liquor	L/min	2,460	5.3	13.0	80.1%
Lime Rock	kg/min	1.30	290	0.38	2.3%
Fuel Oil	L/min	30	97.6	2.9	17.6%
Total:				16.3	
Outputs:					
White Liquor	L/min	1,980	4.1	8.1	41.9%
Weak Wash	L/min	2,400	0.33	0.8	4.1%
Slaker Grits	kg/min	2.9	2,390	5.6	29.1%
Precip catch to sewer	kg/min	3.13	1,950	4.8	24.9%
Total:				19.4	
Lime	kg/min	120	3,200	384	

Phosphorus

Phosphorus is the most important contributor to dead load in the Elk Falls lime kiln. **Table 7** shows that the major sources of phosphorus in the recaust area are the clarified green liquor (79%) and fuel oil (21%). The fuel oil contribution was unexpected. The measured concentration of phosphorus in Elk Falls fuel oil was 550 mg/kg. Since the concentration of zinc is also high in the fuel oil, it is possible that the oil has either been contaminated or that an additive has been introduced to the oil.

Table 7 also shows that the most important purge point for phosphorus is the precipitator catch to sewer (39%). Also important are the grits (30%) and the white liquor (27%). **Table 7** shows that phosphorus input to the recaust area was much greater than output during the August 25/05 mill trial. This is confirmed by the fact that the phosphorus concentration in the lime mud increased from 7,040 mg/kg on May 19 to 7,559 mg/kg on August 25/05 (**Figure 1**). Phosphorus in fuel oil should be as low as possible and the amount of precipitator catch (or other lime mud process stream) sent to sewer must be increased. These are the only ways to reduce phosphorus accumulation in the lime cycle.

For instance, reducing the fuel oil phosphorus concentration to less than 25 ppm would decrease its contribution to about 1% of the total phosphorus input. Time required to reduce phosphorus concentration in lime mud is discussed in the section on NPE inventory.

Table 7. Phosphorus Balance – Clarified Green Liquor to Weak Wash

	Flow Units	Flow Value	P, ppm	P, g/min	% of total
Inputs:					
Clarified Green Liquor	L/min	2,460	26	64.0	79.4%
Lime Rock	kg/min	1.30	61	0.1	0.1%
Fuel Oil	L/min	30	561	16.5	20.5%
Total:				80.5	
Outputs:					
White Liquor	L/min	1,980	7.5	14.9	27.4%
Weak Wash	L/min	2,400	0.8	1.9	3.5%
Slaker Grits	kg/min	2.0	6,890	16.2	29.9%
Precip catch to sewer	kg/min	3.13	8,610	21.3	39.2%
Total:				54.3	
Lime	kg/min	120	12,700	1,524	

Zinc

Zinc is included here as an NPE because it accumulates in the lime cycle and was present at a concentration of 2,240 mg/kg in Elk Falls lime. **Figure 1** shows that zinc concentration in lime mud increased significantly in the year prior to August 25/05. The major zinc input is from fuel oil containing 750 mg/kg of this NPE (**Table 9, Appendix**). High zinc concentrations are not normally expected in fuel oil. Zinc input to the lime cycle was 22 g/min, entirely from fuel oil, while output was only 7.3 g/min, primarily from precipitator catch to sewer and slaker grits. A reasonable specification for zinc in fuel oil at Elk Falls is 200 mg/kg. At this input level, zinc would not accumulate in the lime cycle.

Magnesium

Magnesium concentration in Elk Falls lime mud decreased from 3,450 mg/kg on May 19/05 to 2,820 mg/kg on August 25/05 (**Figure 2**). This is most likely due to lower magnesium concentration in a new lime rock shipment. Elk

Falls began using Texada lime rock on June 25/05. Mass balance results showed that magnesium input to the recaust area was much lower than output. This leads to a reduction in magnesium concentration in the lime and lime mud. At the same time, aluminum concentration in lime mud decreased from 937 to 737 mg/kg. This is because magnesium in the lime mud can form compounds containing both magnesium and aluminum [1,4,11,13]. Aluminum concentration in white liquor decreased over the same period from 41 to 30 mg/L, but it is not clear if this reduction is related to the lower aluminum concentration in the lime mud. No significant change was seen in aluminum concentration in clarified green liquor between May 19 and August 25/05.

4. NPE Inventory

In **Table 8**, the inventory of each NPE is estimated in the recaust area and in mill liquor. These values include all flowing process streams, storage and the recovery boiler bed. For phosphorus, an estimated 2,750 kg of this NPE is present in the recaust area. Only 134 kg is present in the mill liquor.

Table 8. Mill NPE Inventory

NPE, kg	Total Recaust	Total Liquor	Total Mill
Al	503	169	672
Si	1,325	1,028	2,353
Fe	1,252	216	1,468
P	2,748	134	2,882
Ba	149	6	156
Sr	503	<1	503
Mn	145	150	295
Zn	867	9	876

For phosphorus, this means that a process change to increase the loss of phosphorus from the recaust area would result in a fairly slow rate of change of concentration in the lime mud and lime. For instance, to reduce phosphorus concentration by 50%, then 50% of the phosphorus inventory in the recaust area must be removed. That is 1,375 kg of phosphorus. If the net loss of phosphorus in **Table 7** is 10 g/minute, it will take 95 days to achieve this goal.

Aluminum and silicon are distributed throughout the mill, as compared to phosphorus that is primarily in the recaust area **(Table 8).** Reduction strategies for these two elements should consider their mass in the entire mill.

5. Process Changes and Results

Process changes at the Elk Falls mill included the following:

- Improved green liquor clarification
- Increase in kiln precipitator catch to sewer
- Higher quality lime rock
- Fuel oil specifications for P, Fe and Zn

The most cost-effective process change to reduce NPE concentration in the recaust area of the mill was determined to be a temporary major increase in kiln precipitator catch to sewer.

Green liquor clarification improved after May 19/05. A higher quality lime rock source was used starting in June/05. Finally, kiln precipitator catch to sewer was increased significantly beginning February 17/06. It was critical that the high quality of make-up lime rock was maintained during this period.

Figure 1 shows that both phosphorus and zinc concentration in Elk Falls lime mud began to decrease significantly after kiln precipitator catch to sewer was increased on February 17/06. Concentrations of these two NPEs were not significantly affected by green liquor clarification or the new lime rock source, as expected.

Figure 2 shows that magnesium, iron and aluminum concentration in Elk Falls lime mud began to decrease after May 19/05. The decrease in magnesium concentration in lime mud is due to lower concentrations of this element in the makeup lime rock. Lower magnesium concentrations likely caused the reduction of aluminum concentrations in the lime mud. Iron concentration decreased slightly with improved clarifier operation after May 19/05. Based on the results in **Table 6**, iron in lime mud will continue to slowly decrease as long as the iron concentration in the clarified green liquor remains below about 6 mg/L. With increased precipitator catch to sewer after February 17/06, iron concentration in lime mud decreased at a higher rate. Within experimental error, silicon concentration in the lime mud did not change. This was expected based on the similar concentrations of silicon in the lime rock and the lime mud (**Table 9, Appendix**).

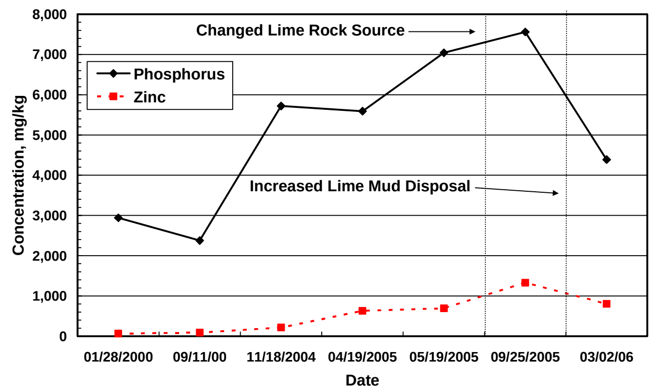

Figure 1. Trends in P and Zn in Elk Falls Lime Mud

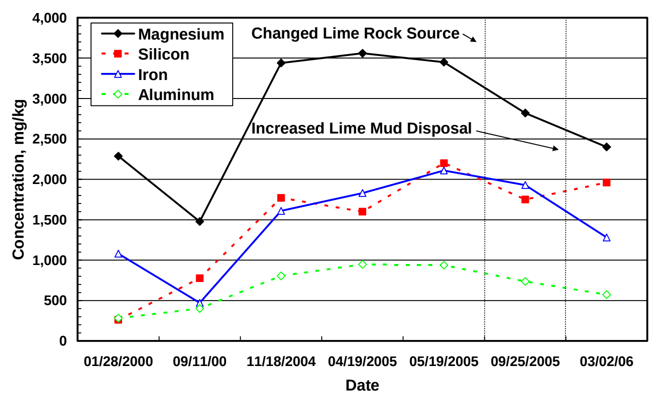

Figure 2. Trends in Mg, Si, Fe and Al in Elk Falls Lime Mud

Sewering of kiln precipitator catch had a definite positive impact on solids content of lime mud as shown in **Figure 3**. Precipitator catch slurry initially flowed to sewer beginning in February 2005 and ending September 20, 2005. During this period, lime mud solids averaged 76.2% with a standard deviation of 2.3%. The slurry line plugged on September 20 and was not put back into operation until February 17, 2006. While the line to sewer was out of commission, lime mud filter solids continuously declined, averaging 72.9% with a standard deviation of 1.9% from January 17 to February 17, 2006. After February 17, slurry flow was restarted at a high rate. Average slurry flow rate was 55 L/minute from February 17 to March 31, 2006, replacing an estimated 40% of the lime mud inventory. Lime mud solids from March 16 to March 31, 2006, averaged 76.4% with a standard deviation of 1.8%. These results show a significant improvement in lime mud solids content. Phosphorus, zinc, iron and aluminum concentrations in the lime mud all decreased significantly by March 2/06 as shown in **Figures 1 and 2**.

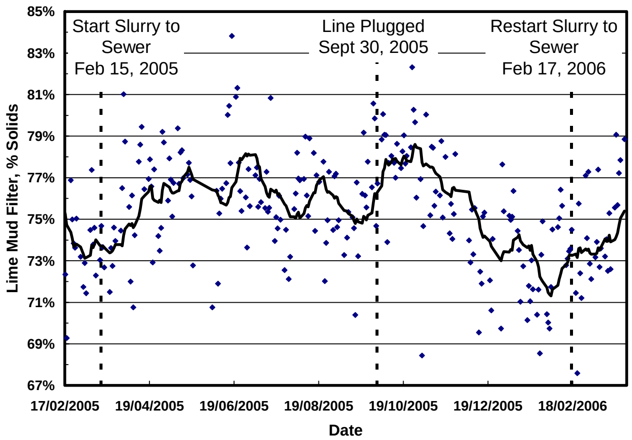

Figure 3. Lime Mud Solids Content, 10 Day Average

Conclusions

- NPE mass balance identified the most cost-effective strategies to increase lime mud solids content and reduce kiln dead load at Elk Falls mill.
- NPE mass balance enabled NPE specifications for lime rock, fuel oil, salt cake, and clarified green liquor.
- Fuel oil was identified as an important source of P, Fe and Zn in the Elk Falls lime cycle.
- Lime rock and salt cake do not currently contribute significantly to NPE input at Elk Falls.
- Major NPE inputs and outputs in Elk Falls recaust area were identified.
- Adding magnesium ion to the dissolving tank could reduce mill levels of Al and Si at Elk Falls mill.

Recommendations:

- Increase precipitator catch to sewer to operational maximum until NPE levels reach target.
- Maintain iron concentration in clarified green liquor at less than 6 mg/L.
- Implement fuel oil specifications: P < 25 mg/kg, Zn < 200 mg/kg, iron < 50 mg/kg.
- Lime rock specifications: Fe < 300 mg/kg, Si < 2,000 mg/kg, Al < 200 mg/kg, P < 100 mg/kg, Mg < 5,000 mg/kg (currently within specifications).
- Salt cake specifications: P < 200 mg/kg, Si < 200 mg/kg, Al < 200 mg/kg (currently within specifications).

REFERENCES

1. TAYLOR, K. and McGUFFIE, B., "Investigation of Non-Process Element Chemistry at Elk Falls Mill – Green Liquor Clarifier and Lime Cycle", *PAPTAC Parksville Conference*, April 21-22, 2006, *PACWEST Conference*, Jasper, AB, May 17-21, 2006.
2. JEMAA, N., THOMPSON, R., PALEOLOGOU, M. and BERRY, R.M., "Non-Process Elements in the Kraft Cycle, Part I: Sources, Levels and Process Effects", *Pulp & Paper Canada*, 100(9): 47-51 (1999).
3. ULMGREN, P., "Non-Process Elements in a Bleached Kraft Pulp Mill with Increased System Closure", *Tappi Minimum Effluent Mills Symposium Proceedings*, Atlanta, Georgia, 17-26 (1996).
4. RICHARDSON, B., ULOTH, V., LOWNERTZ, P., GLEADOW, P., FORGET, C. and HOGIKYAN, R., "Behaviour of Non-Process Elements in the Kraft Recovery System", *TAPPI Proceedings, 1998 International Chemical Recovery Conference*, Tampa, FL, 1025-1039.
5. KEITAANNIEMI, O. and VIRKOLA, N.E., "Undesirable Elements in Causticizing Systems", *TAPPI*, 65(7), 89-92 (July 1982).
6. KEITAANNIEMI, O. and VIRKOLA, N.E., "Amounts and Behaviour of Certain Chemical Elements in Kraft Pulp Manufacture: Results of a Mill Scale Study", *Paperi ja Puu*, 60(9), 507-522 (1978).
7. MAGNUSSON, H., MÖRK, K. and WARNQVIST, B., "Non-Process Elements in the Kraft Recovery System", *Proc. 1979 TAPPI Pulping Conference*, Sept. 24-26, Seattle, WA, p. 77-83.
8. FREDERICK, W.J. Jr., "Managing Non-Process Element Flows in Pulp-Mill Operations", in: *The Impact of Energy and Environmental Concerns on Chemical Engineering in the Forest Products Industry*, AIChE Symposium Series, No. 239, Vol. 80, 21-29 (1984).
9. ERICKSON, L.D. and HOLMAN, K.L., "Non-Process Element Flows and Control in a Kraft Pulp Mill", in: "*Applications of Chemical Engineering Principles in the Forest Products and Related Industries*", Ferhan, K., Krieger-Brockett, B., Eds., AIChE Forest Products Division, New York, Vol. 1, 21-30 (1986).
10. ELLIS, M. MURNANE, M. and GLEADOW, P., "Towards Kraft Mill Closure: Inorganic Element Balance for Tasman Pulp and Paper Company Ltd.", *Pulp & Paper Canada*, 100(7): T206-210 (1999).
11. TAYLOR, K. and BOSSONS, D., "Investigation of Green Lime Mud at Harmac Mill", *Pulp & Paper Canada*, 107(3): T63-66 (2006).
12. VÄLTTILÄ, O., JAARMO, S., JÄRVINEN, R. and KIISKILA, E., "Removal of Silica from Bleach Plant Filtrates", *Tappi Minimum Effluent Mills Symposium Proceedings*, Atlanta, GA, 309 (January 1996).
13. ULMGREN, P., "The Removal of Aluminium from the Recovery System of a Closed Kraft Pulp Mill", *Nord. Pulp Pap. Res. J.*, 2(1), 4-9 (1987).

APPENDIX

Table 9. Results of Elemental Analysis (Solids Basis)										
Element, mg/kg	Weak Black Liquor	Strong Black Liquor	Salt Cake	Dregs	Lime Mud	Lime	Lime Rock	Slaker Grits	Kiln Precip. Catch	Fuel Oil
Al	75	85	< 5	2,050*	737	1270	152	968*	735	23.4
Ba	2.5	3.6	< 1	56	232	378	1	202	247	15.9
B	< 50	< 50	< 50	50	10	17	11	13	15	< 5
Ca	279	440	150	20,700*	380,000	619,000	387,000	370,000*	390,000	1,230
Cr	< 1	< 2	< 2	42	20	31	8	19	22	2.5
Cu	< 2	2	< 2	110	24	45	40	23	34	29.2
Fe	127	132	< 5	10,600*	1,930	3,200	290	2,390*	1950	97.6
Pb	< 10	< 10	< 10	7	28	50	<10	11	75	20.4
Mg	156	239	402	12,100*	2,820	4,660	2,010	3,000*	2,730	25.5
Mn	82.4	91.9	< 1	5,950*	221	360	35.6	172	216	2.2
Mo	< 20	< 20	< 20	< 20	< 10	< 10	<10	< 10	14	24
Ni	< 5	< 5	< 5	38	< 50	< 50	<50	< 50	< 50	8.1
P	60	70	< 20	78	7,559	12,700	61	6,890*	8,610	574/548**
K	7,770	7,500	77	11,600	22	84	25	997	91	26.1
Si	368/489*	465/424*	< 10	5,190*	1,750	2,990	1,530*	2,570*	2,050	30.6
Na	210,000	209,000	334,000	267,000	7,300	12,400	<200	30,200	9,900	< 100
Sr	< 5	< 10	< 10	114	783	1,270	839	761	831	1.2
Ti	0.64	0.94	0.08	127	23	39	2.8	23	25	1.2
V	9	8.2	< 1	13	17	28	18	18	31	19
Zn	4.5	6	< 1	313	1,330	2,240	13	1,120	1,660	725/786**

*fused **repeat analysis. As, Cd, Co, Li < 5 mg/kg.

Table 10. Results of Elemental Analysis (Liquid Samples)							
Element, mg/L	Raw Green Liquor	Clarified Green Liquor	Filtered Clarified Green Liquor*	White Liquor	Duplicate White Liquor	Weak Wash	Dregs Filtrate
Al	38	30	29.7	29.5	29.6	5.1	2.4
B	13	14	14	13	13	2	< 10
Ca	67	10	9	10	10	2.5	206
Fe	49.8	5.3	2.4	4.1	4.1	0.33	2
Mg	63.9	0.43	< 0.1	0.7	0.71	0.02	1.77
Mn	30.8	4.2	1.7	4.4	4.5	0.1	0.3
P	25	26	26	7	8	0.8	44
K	3,560	3,790	3,780	3,580	3,590	734	1710
Si	282	282	282	289	288	64.2	67.4
Na	94,900	101,000	101,000	97,600	98,000	19,600	46,300/45,500**
V	3.97	4.24	4.2	4.23	4.24	0.97	2

**repeat analysis. *A portion of the clarified green liquor was filtered through a Whatman 542 filter paper on Aug. 25/05. As, Mo, Pb, Zn < 2 mg/L. Ba, Cd, Co, Cu, Li, Ni, Sr, Ti < 1 mg/L. Cr < 0.2 mg/L.