ENERGY REDUCTION IN MECHANICAL PULPING

APRIL 2016

UBC100

THE UNIVERSITY OF BRITISH COLUMBIA

Welcome Message

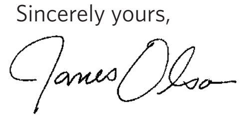
Dear partners in the Energy Reduction in Mechanical Pulping research program,

We have had another busy and successful five months since we last met at our Steering Committee meeting on the UBC campus. The program is now halfway completed and we will soon be looking forward to our next phase. Ramin Khoie has successfully completed his MASc in Mechanical Engineering, while Nicholas McIntosh, UBC, and Hanya Ettefagh, UofT, are close to completing their respective MASc degrees. The other researchers have made great progress to date and are working toward their goals of pilot plant trials and mill trials, which they describe in their project updates in the pages ahead. We have had several publications from the program in recent months, as well as participation in conferences. I invite you to explore these on pg. 21 of our Program Updates. Another successful set of trials was completed at the Andritz R&D Center in December 2015, with data currently under analysis and some follow-on work with collected samples being carried out. We expect to share some interesting publications with the partners in coming months. UBC's new Master of Engineering Leadership (MEL) in Green Bio-Products professional program successfully launched in January 2016 with a cohort of five students, including an employee from Canfor Pulp. To learn more about this program, please contact Prof. Mark Martinez who is the current Director of the Green Bio-Products program.

I recently had the opportunity to visit a series of pulp and paper companies in Brazil that included Fibria, Klabin, International Paper and Suzano Papel e Celulose. I was extremely impressed with the commitment to research and innovation these companies demonstrated. The pulp and paper industry in Brazil is leveraging their current strength to implement advanced genomics technology that will enhance their fibre supply, as well as, to develop advanced biomaterials and biochemicals that will diversify their revenues.

Finally, I would like to extend an invitation to all of our partners to Pulp and Paper Centre's 30th Anniversary celebrations – May 27th we are hosting a dinner with alumni and industry guests, and May 28th we will open our doors to the public for an Open House. More details can be found on pg. 4. I hope to see all of you in May, and then again in June in Jasper, AB for our bi-annual Steering Committee meeting at the Pacwest Conference.

Sincerely yours,



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ON THE COVER
Howe Sound, indication of Squamish's rich forestry heritage that played a pivotal role in the development of the community.
Photo: Anna Jamroz

UBC's PULP AND PAPER CENTRE 30TH ANNIVERSARY MAY 28, 2016

Join us at the Open House for a day of celebrating this milestone and the remarkable achievements of our PPC community. The Open House will give our alumni and invited guests the opportunity to reconnect and network with their peers, faculty members, and today's talented students, and it will also give students the opportunity to meet PPC alumni and industry professionals in a fun and informal setting. There is no cost to attend the Open House and all registered participants will receive a light lunch. The Open House program includes special seminars by Dr. Richard Kerekes, PPC's first director; Dr. Mark Martinez, current director, Dr. James Olson and Dr. Heather Trajano. Interactive lab tours, graduate student poster session, handsheet making for the whole family and so much more! To download the program, visit www.ppc.ubc.ca/ppc30.

The Centre is also organizing an Alumni & Guests Dinner the night before the Open House.
You can join us at both events, or as your schedule permits

We've lost touch with some of our alumni and need your help! Please help us spread the word to anyone who you still keep in touch with. We hope to see you all in May.

Open House Event Details:
Saturday May 28th, 2016
11:00-5:00 pm
(Join us for the whole day, or stay for a while)
Pulp and Paper Centre
2385 East Mall, Vancouver

Alumni & Industry Dinner Details:
Friday May 27th, 2016
6:00-10:00 pm
Vancouver BC
Cost of $100 per person associated with this event

RSVP at: www.ppc.ubc.ca/ppc30

NICHOLAS McINTOSH

1.1 - COMPRESSION SCREW FEED OPTIMIZATION AND ENERGY SAVINGS IN HC REFINING

Compression of woodchips prior to refining has been shown to be an effective method by which to reduce refining energy requirements [1]. If coupled with an impregnation process following compression, refining energy requirements have been observed to be further reduced [2]. To better understand the relationship between compression conditions and product properties (e.g., liquid uptake capacity of compressed chips) an optical approach involving microscope imaging and image analysis has been taken to obtain pore-size distributions of the treated chips. The obtained pore-size distributions allow for liquid uptake capacities to be predicted and the microstructure of the chips to be related to the compression conditions which produced them. A second, complementary, method has also been developed which directly measures liquid uptake capacity. The combination of the two compressed-chip characterization methods will allow for a fuller picture of chip destructuring mechanism to be painted and allow for an optimum (in terms of enhanced liquid uptake) to be determined in terms of compression conditions and, indeed, screw press operating conditions.

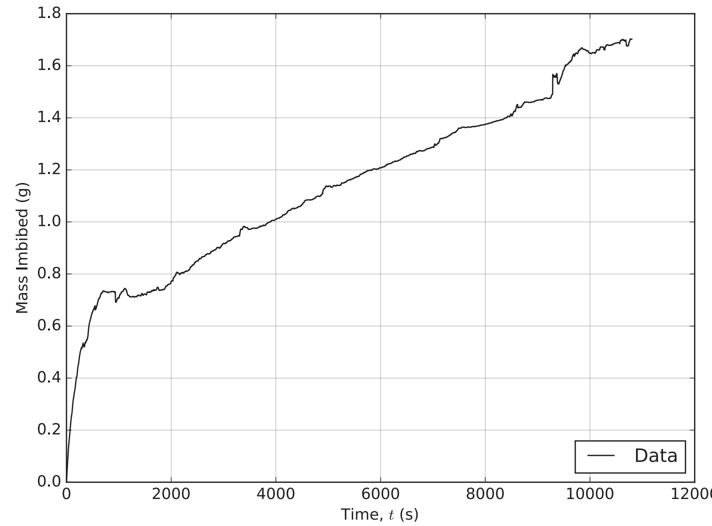

Figure 2: Mass uptake over time of wooden samples as measured with the in-lab setup at UBC's Pulp and Paper Centre. Though conceptually simple, the data collected allows for detailed structural information about the wood to be calculated.

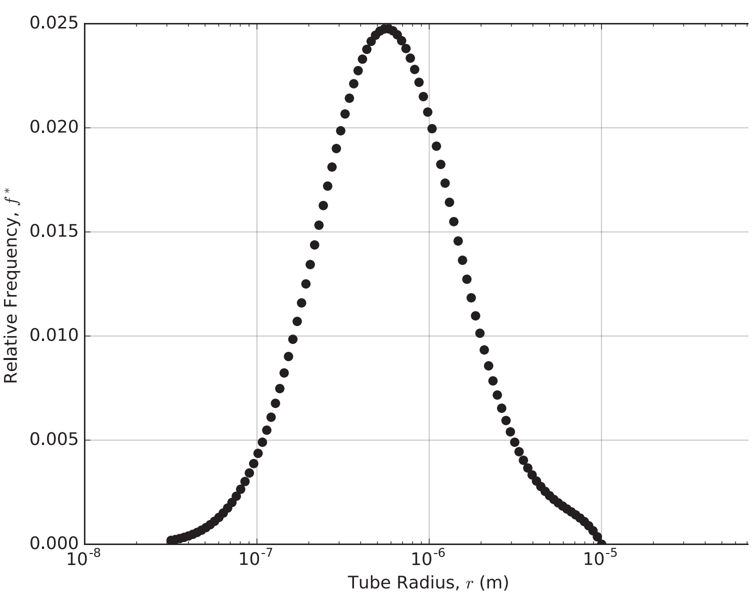

Figure 1: Pore-size distribution back-calculated from liquid uptake data of a wooden sample.

Liquid Uptake Experiments

Currently, experiments to characterize the liquid uptake capacity of compressed wood samples are underway. By directly controlling the compression conditions the wood undergoes before liquid uptake using a lab-scale hydraulic piston, it is possible to illuminate trends in destructuring of wood that occur over ranges of total amount of compression imparted to the chips, and how fast they are compressed which may not be as clear when only looking at industrially produced chipettes.

The liquid uptake experiments are simple in design – wood samples are connected to a liquid reservoir and their mass is monitored with time. Any mass gain is thus due to liquid uptake. These experiments provide not only the direct measurement of how a given compressive treatment may result in enhanced, or stifled, liquid uptake ability of the wood, but also provide data for the calculation of a pore-size distribution, which may be thought of as a quantification of wood's structure which allows for numerical comparison and simulation of liquid uptake ability.

With the pore-size distributions from the liquid uptake experiments as well as those obtained from past image analysis work, it will be possible to draw parallels between already-collected mill scale results and those from the (currently underway) full matrix of lab scale experiments; ultimately, an optimum in compression conditions may be found and liquid uptake may be maximized.

References
[1] Dmitri Gorski. ATMP Process: Improved Energy Efficiency in TMP Refining Utilizing Wood Disintegration and Targeted Application of Chemicals. PhD thesis, Mid Sweden University, 2011.
[2] Erik Nelsson. Reduction of Refining Energy during Mechanical Pulping. PhD thesis, Swedish University of Agricultural Sciences, Uppsala, 2011.

YU SUN & HARRY CHANG

1.3 - OPTIMIZATION OF CHEMICAL CHARGE DISTRIBUTION THROUGHOUT THE PROCESS

Since November 2015, progress has been made in several aspects, including chemical application in LC reject refining (based on Andritz trial 2015), two-stage alkaline peroxide treatment high-freeness TMP, and characterization of LC refined pulp produced from chemically pretreated wood chips (based on Andritz trial 2014).

During the 2015 Andritz trial the main goal was to evaluate the energy efficiency of low consistency refining of reject pulps produced with four different screen sizes for pulp fractionation. The reject pulp from one of the runs has been selected as the feedstock for research work designed to evaluate the effects of chemical treatment on subsequent low consistency refining. This reject pulp was collected using a screen with 1.0 mm diameter holes and a reject rate by volume of 28.8%. The experimental plan for the chemical treatment and refining trials is currently under design. After choosing the most promising chemical treatment, a pilot plant scale trial of LC refining on chemical treated reject pulp will be conducted at UBC Pulp and Paper Centre's pilot plant.

In preliminary work, two-stage alkaline peroxide treatment on high freeness pulp showed positive effect on improving both strength and optical properties. Further research work under this direction is ongoing, and the focus is on evaluating the effects of different reaction conditions (reaction time, temperature and ratio of sodium hydroxide to peroxide - $NaOH/H_2O_2$). At this stage, all the trials of two-stage alkaline peroxide treatment are using TMP pulp from Holmen's Braviken mill.

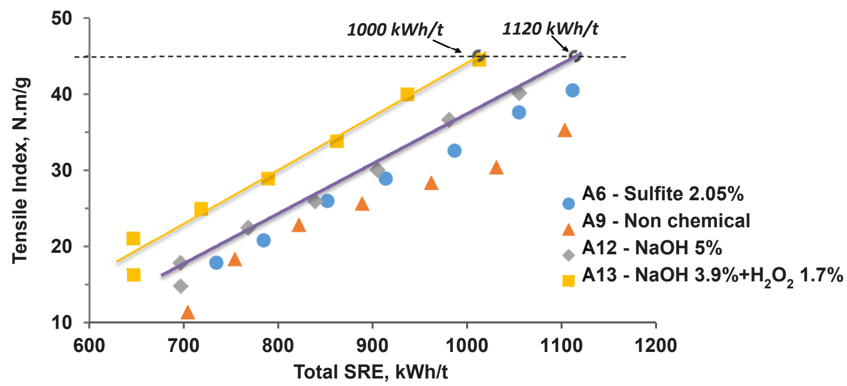

Figure 2: Effects of chemical pre-treatments of wood chips on the energy consumption of certain tensile index of Low Consistency Refined TMP

During 2015 the primary pulp produced from chemically treated and non-treated chips in the Andritz pilot plant was LC refined at UBC's Pulp & Paper Center. Based on the data on the primary and LC refined pulps, two abstracts have been submitted to the International Mechanical Pulping Conference 2016. The first paper is focused on analyzing pulp qualities after HC refining and is titled, 'A Pilot Scale Comparison of the Effects of Chemical Treatments of Wood Chips on the Properties of High Freeness TMP'. The second paper focuses on analyzing pulp qualities after LC refining and is titled, 'A Pilot Scale Comparison of the Effects of Chemical Pre-treatments of wood chips on the properties of low consistency refined TMP'.

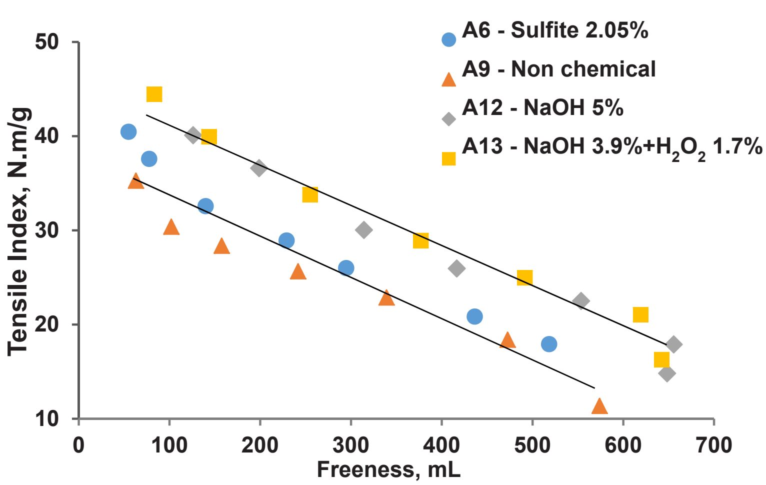

Figure 1: Effects of chemical pre-treatments of wood chips on the tensile index of LCR TMP

A paper titled 'Study on alkaline oxygen treatment of high freeness TMP pulp followed by lab-scale Low-consistency Refining' was presented by Yu Sun during PaperWeek, February 2016 in Montreal, Quebec.

JORGE RUBIANO

1.4 - OPTIMAL LC REFINING

2015 Andritz trials & Comminution Model results

Low consistency refining is a very heterogeneous process due to the forces imposed on fibres. This can lead to various structural changes, fibre shortening being one example and perhaps the most important since almost all pulp properties (e.g. tensile, bulk, light scattering, formation) are strongly dependent on the fibres' length and in some cases, it can have negative impacts on the properties of interest.
To date, most of the studies about fibre shortening have used fibre average length to assess it. A rigorous approach is to consider the fibre shortening a combination of two phenomena: (1) probability of breakage and (2) re-distribution of shorter fibres. These two concepts constitute the core of a comminution model.

During December 2015, a total of nine refining trials were carried out at the Andritz R&D Center in Springfield, Ohio. Pulp was screened using four different baskets. The reject pulp was LC refined in stages at a constant intensity using a 22" double disk refiner with Andritz Durametal T101/T102 plates. Unscreened pulp was refined as a control. Two levels of LC refining intensities were explored (0.50 and 0.25 J/m). The intensity target was achieved by varying the gap. The rotational speed and flow rate were kept constant for all trials at 1035 RPM and 660 L/min respectively. These trials are summarized in Table 1:

Trial	Screen	LCR Intensity (J/m)
1	-	0.50
2	-	0.25
3	Holes 0.8mm	0.50
4	Holes 0.8mm	0.25
5	Holes 1.0 mm	0.50
6	Holes 1.0 mm	0.25
7	Holes 1.2 mm	0.50
8	Holes 1.2 mm	0.25
9	Slots 0.15mm	0.50

Table 1: Summary of trials carried out at Andritz R&D Center

The data collected constitutes an important part of this project because it allows us to estimate the comminution model parameters related to the cutting rate and cutting location. It was also possible to estimate the screening model parameters (models available in the literature) from the obtained screening results.

The 2015 Andritz refining trials were analyzed using a comminution model. Figure 1 shows estimates of specific cutting rates for the mean gap used during the Andritz 2015 refining trials (blue and red markers).

They are plotted together with seven previous refining trials conducted at UBC's Pulp and Paper Centre. The graph shows a strong correlation between the cutting rate and the refiner gap; the cutting rate increases exponentially as the gap between the refiner plates decreases. These findings agree with studies in literature where it was stated that fibre shortening is directly affected by the gap; however, the nature of the relationship had never been described until now.

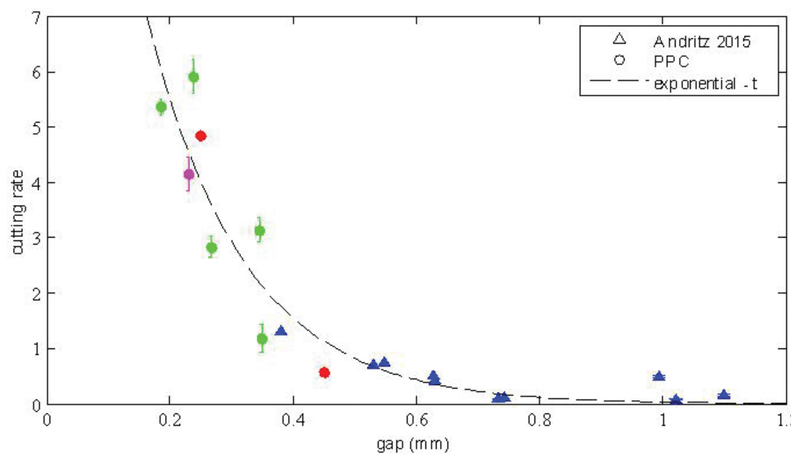

Figure 1: Specific cutting rate as a function of gap. Each single marker corresponds to a refining trial at different refining conditions. Same color used the same plates. Triangles are Andritz 2015 trials, circles are PPC trials. Dashed-line is a proposed exponential fit

Furthermore, it was also found that the cutting location seems to be related to the gap. Small gaps favor cutting at the middle points whereas wider gaps favor cutting in the tails of the fibres.

With these findings, it is possible to predict the fibre shortening by knowing the operational conditions such as refiner plates, volumetric flow, gap, and rotational speed. These results are potentially useful in LC refining because they can set the basis for tailoring fibre length distributions allowing future correlations to pulp properties (e.g. bulk, tensile strength).

1.4 CONT.

Analysis of complex refining systems

The comminution model was used along with screening models available in literature in order to analyze more complex refining systems (i.e. refining with screening, see figure 2). As can be seen, with combined models, it is possible to fully describe fibre length distribution changes at every unit operation (refiner, screen, mixing point, etc.) at a wide range of conditions.

Ultimately the strategy is to relate the fibre length to the important pulp and paper properties such as tensile, bulk, and drainability in order to find an optimum operation point for every refining system analyzed.

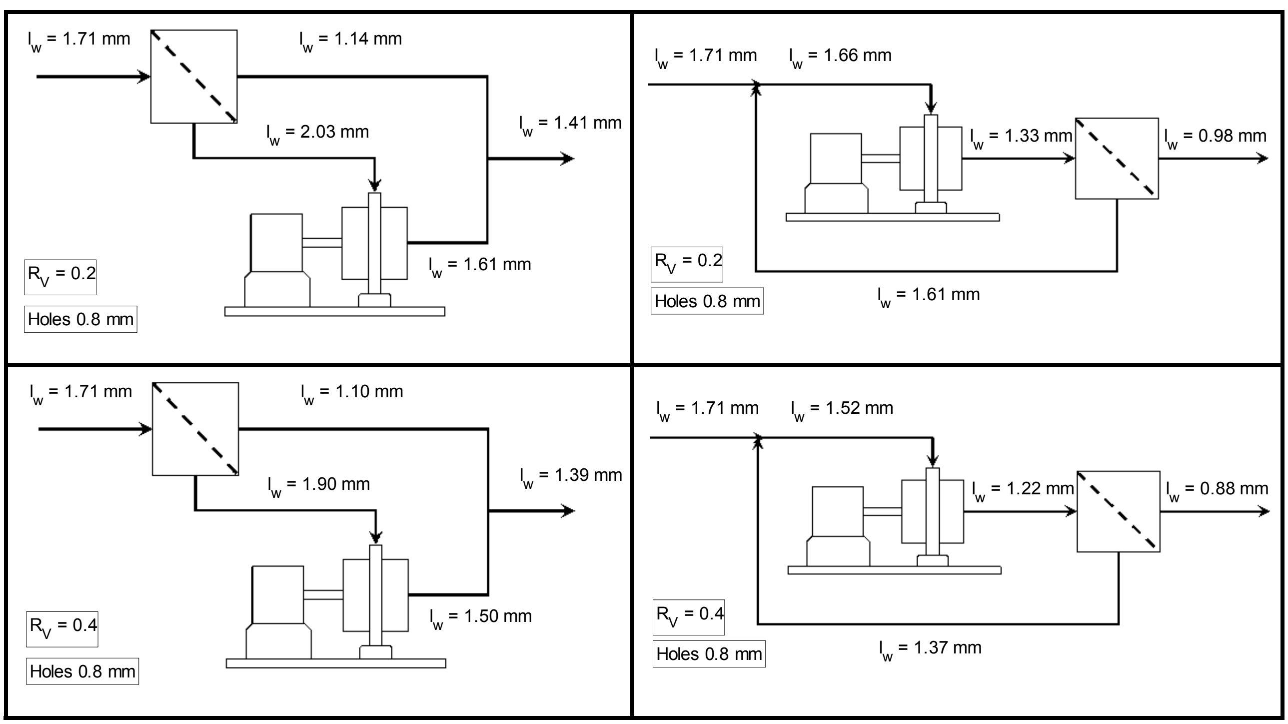

Figure 2: Analysis of two [refiner]-[screen] systems using a comminution model and screening model. In the top frames R_v=0.2, in the bottom frames R_v=0.4.

HUI TIAN

2.1 - OPTIMIZATION AND CONTROL OF INTEGRATED HC AND LC REFINING

Project 2.1 aims to reduce energy consumption in the mechanical pulping (MP) processes by developing an advanced economic model predictive control (*econ* MPC) technique. We have previously built a dynamic nonlinear model for a two-stage (primary and secondary) high consistency (HC) refining process. The MP process is a complex multi-input-multi-output (MIMO) nonlinear process with strong interactions among the variables. In this two-stage MP model, the production rate, motor loads and consistencies for both primary and secondary refiners are chosen as the discretized differential state variables while the pulp properties after each refiner are treated as the algebraic state variables. The chip-transfer screw speed, plate gap and dilution water flow rates of each refiner are taken as the manipulated variables. The linear dynamics of the discretized differential state variables and disturbances are modeled using data collected from several identification experiments on industrial processes. The discrete-time nonlinear model for the two-stage MP process at time can be written as,

$$\begin{aligned} x_{t+1} &= Ax_t + h(x_t, u_t) = f(x_t, u_t), \\ 0 &= g(x_t, y_t), \end{aligned} \tag{1}$$

where x_t, u_t and y_t and are the state variable, manipulate input variable, and output variable, respectively. $h(\cdot)$, $f(\cdot)$, and $g(\cdot)$ are the system nonlinear functions.

Building on our previous work on the *econ* MPC algorithm for a two-stage HC MP process, we are now focusing on how to guarantee the stability and convergence of the closed-loop nonlinear MP process. Two different *econ* MPC schemes are proposed: one with penalty on the increment of the input and one with penalty on the offset of the input from its steady-state target (this work has been accepted by the 2016 American Control Conference [1]). We demonstrate that both *econ* MPC schemes achieve significant reduction in specific energy consumed by the MP process. However, in order to reduce the specific energy consumption, a larger penalty has to be added to the economic term in the objective function. This may lead to a significant deviation of the state variables from the steady-state target. Similar issues have also been reported in literature [2] [3]. This motivated us to develop the multi-objective economic MPC (*m-econ* MPC) which achieves an acceptable compromise between the tracking performance and the economics.

In the *m-econ* MPC technique, an auxiliary MPC controller and a stabilizing constraint are incorporated into the *econ* MPC scheme. The stability of the *m-econ* MPC is achieved by preserving the inherent stability of the auxiliary MPC controller. The *m-econ* MPC dynamic optimization problem is formulated as follows,

$$\begin{aligned} &\min_{z_k, v_k} \sum_{k=t}^{t+T-1} S_k \\ \text{subject } to \quad & z_0 = x_{t+1},\ z_T = x_s \\ & z_{k+1} = f(z_k, v_k),\ 0 = g(z_k, v_k), \\ & x_{min} \le z_k \le x_{max}, \\ & y_{min} \le y_k \le y_{max}, \\ & u_{min} \le v_k \le u_{max}, \\ & \sum_{k=t}^{t+T-1} \| z_k - x_s \|_{Q_x}^2 + \| v_k - u_s \|_{Q_u}^2 \le \epsilon_{t+1}(\sigma), \\ & \epsilon_{t+1}(\sigma) := \bar{V}_{t+1}^{tr} + \sigma(V_t^{tr} - \bar{V}_{t+1}^{tr}), \\ & k = 0, \ldots, T-1, \end{aligned} \tag{2}$$

where S_k is the specific energy, which is defined as the ratio of total motor load to the production rate. z_k and v_k are the internal optimization variables for the states and inputs, respectively. $f(\cdot)$, and $g(\cdot)$ are the system dynamics and defined in (1). x_{min}, x_{max}, y_{min}, y_{max}, u_{min} and u are the lower bounds and upper bounds for the states, outputs and inputs, respectively. $\bar{V}_{t+1}^{tr}$ is the optimal value function, which can be obtained by solving the standard tracking MPC problem. σ is a scalar in between $[0,1)$. Q_x and Q_u are the weighting matrices for the state and manipulate variables, respectively. T is the prediction horizon.

In the closed-loop simulation, the variations in the raw materials such as the chip bulk density and the chip solid content are considered as the disturbances. As mentioned in the definition (2), the scalar σ has to be in the range [0,1) for closed-loop stability. However, to demonstrate the effect of the parameter σ on the tracking performance and the economics, here we allow $\sigma = 1$ and will examine the following four different values of σ: $\sigma = 0$, $\sigma = 0.5$, $\sigma = 0.75$, and $\sigma = 1$. Note that for $\sigma = 0$, the *m-econ* MPC will be reduced to the standard tracking MPC. When $\sigma = 1$ it will be equivalent to the *econ* MPC without regulations. $\sigma = 0.5$ and $\sigma = 0.75$ are the two cases where we have the standard *m-econ* MPC. To address the computational issues, in this simulation the nonlinear MP process model is built in AMPL (A Mathematical Programming Language), and the nonlinear optimization problem is solved using IPOPT (Interior Point Optimizer).

2.1 CONT.

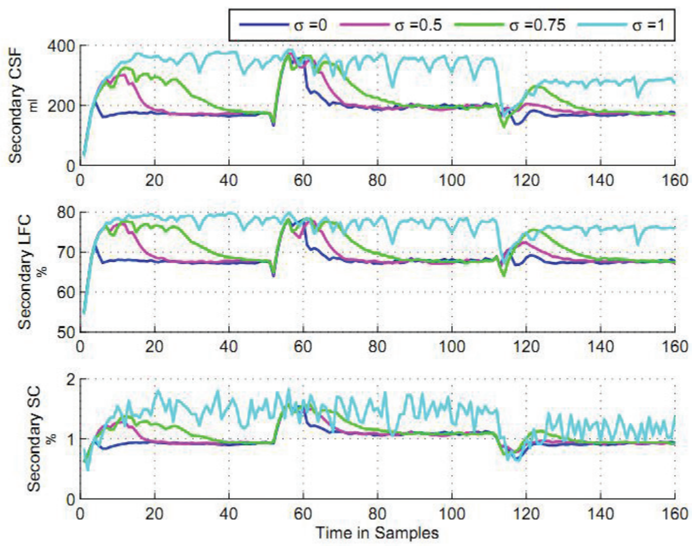

Figure 1: Pulp properties after the secondary HC refining process

The simulation results are shown in Fig.1--3. From Fig.1, we can see that for these four situations, all of the pulp qualities such as the Canadian standard freeness (CSF), long fibre content (LFC), and shive content (SC), remain within their respective acceptable ranges: 50-400ml, 50-80%, and 0-2%. However, by using the *econ* MPC ($\sigma = 1$) the pulp qualities are more likely to hit the limits compared with the other three MPC schemes. This is not desirable from the perspective of mechanical pulping mills.

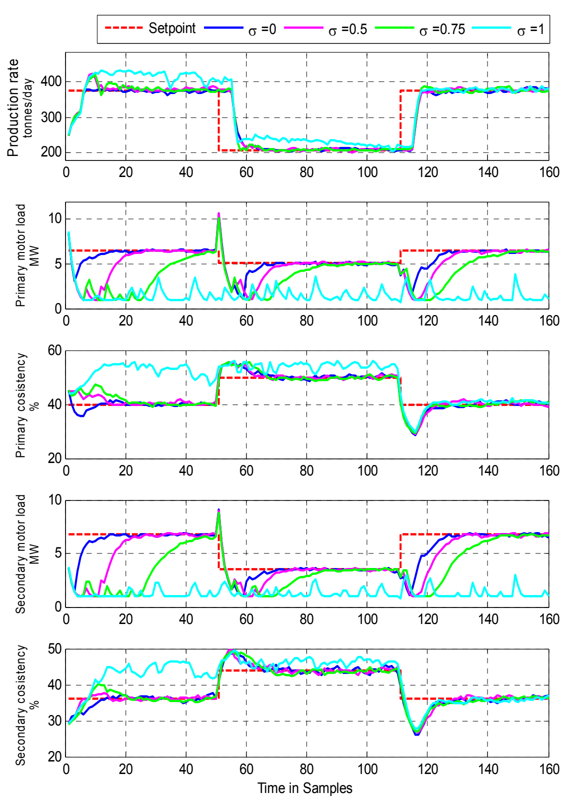

Figure 2: The state variables of the MP process

Fig. 2 illustrates the tracking performance of the state variables. It can be seen that for $\sigma = 0$, $\sigma = 0.5$ and $\sigma = 0.75$, the state variables converge to the steady state but with different convergence speed. Specifically, as σ decreases, the tracking speed of the *m-econ* MPC improves. For the extreme case where $\sigma = 1$, the convergence and stability cannot be guaranteed since the target in this case will be merely achieving the optimal economic performance regardless of the tracking performance or even the stability. Thus, the case when $\sigma = 1$ is just for reference only since it does not represent a real situation.

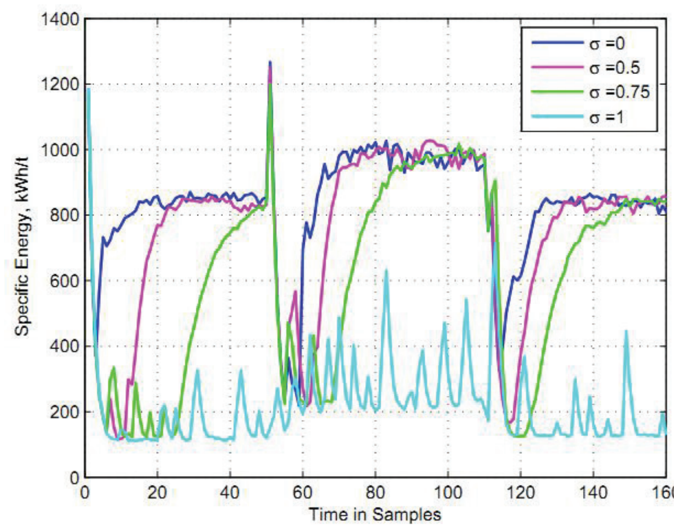

Figure 3: Specific energy comparison

The comparison of the specific energy consumption is illustrated in Fig.3. From Fig.3, we can see that the *m-econ* MPC with $\sigma = 0.5$ and $\sigma = 0.75$ can save about 10% and 27% of the specific energy, respectively, compared with the tracking MPC when $\sigma = 0$.

We are now analysing the industrial data from our partner at Alberta Newsprint Company and testing our proposed *m-econ* MPC technique. Based on the rather encouraging simulation results, we are planning to conduct a pilot trial on a conventional HC refining process in the near future.

References

[1] H. Tian, Q. Lu, R.B. Gopaluni, V.M. Zavala, and J.A. Olson, “Economic nonlinear model predictive control for mechanical pulping process”, American Control Conference, accepted, 2016.

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REZA HARIRFOROUSH

2.2 - LC REFINER BAR FORCE SENSOR BASED CONTROL STRATEGIES

This study aims to understand the relation between refiner control variables, local bar forces and resulting pulp properties, and to develop new refiner control strategies that exploit the latest generation of the Refiner Force Sensor (RFS) to reduce fibre cutting and increase the energy efficiency in low consistency (LC) refining.

Based on data collected at the UBC-PPC February 2015 trials, Harirforoush et al. [1] found that, as the plate gap is reduced, the net refiner power and the mean peak normal and shear forces increase but the length-weighted fibre length remains relatively constant. When the mean peak normal and shear forces reach the threshold values, a transition occurs. Above these thresholds, mean peak normal and shear forces continue to increase but the length-weighted fibre length exhibits negative linear relationships with these forces. However, these trends were based on a limited range of operating conditions.

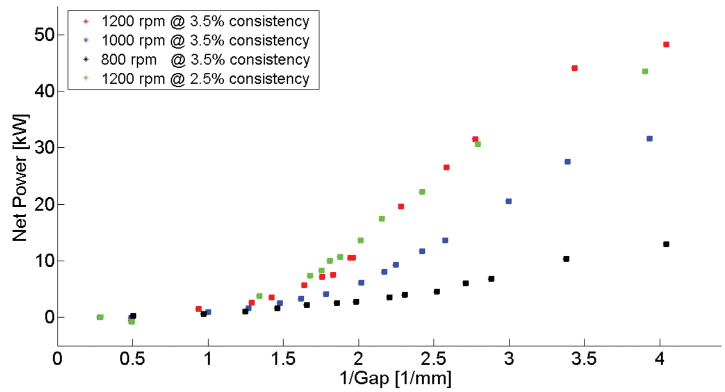


Figure 1: Net power versus the inverse of the plate gap

Table 1: Operating conditions for the low consistency refining trials at UBC		
Parameter	Plan A	Plan B
Refiner speed	1200 rpm, 1000 rpm, 800 rpm	1200 rpm
Consistency	3.5 %	2.5 %
Flow rate	250 l/min	
Plate gap	1200 rpm, 3.5 mm - 0.25 mm (15 gaps) 800 rpm, 3.5 mm - 0.25 mm (15 gaps) 1000 rpm, 3.5 mm - 0.25 mm (15 gaps)	1200 rpm, 3.5 mm – 0.25 mm (12 gaps)
Pulp type	Mechanical SPF softwood pulp, 378 ml CSF	

To explore a wider range of operating conditions, further trials were conducted in November 2015 at UBC's Pulp and Paper Centre's AIKAWA 16″ single-disc LC refiner. The operating conditions for these trials are shown in Table 1. The sensors measure the normal force to the plate surface (i.e. parallel to the axis of the refiner) and the shear force perpendicular to the major axis of the refiner bar.

Relation between net power and inverse of the plate gap:
The relationships between the net power and the inverse of the plate gap are shown in Fig 1. These relationships are similar to the result of Elahimehr et al. [2]. As the plate gap is reduced, the net power increases. At a constant gap, increasing the rotational speed increases the amount of energy transferred to the fibres. The critical gap, G_C, which is characterized by the onset of significant fiber cutting, is not apparent in these plots.

The relation between length-weighted fibre length and inverse of the plate gap:
The relationships between the Length-weighted fibre length (L_w) and the inverse of plate gap is depicted in Fig 2. Comparing the critical gaps for these trials shows that the G_C is lower for lower rotational speeds. This finding is consistent with the results of Elahimehr et al. [2] and Nugroho [3].

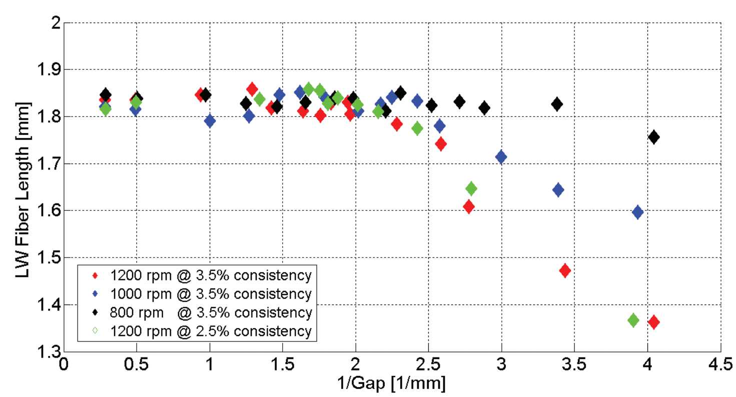


Figure 2: Length-weighted fibre length versus the inverse of the plate gap

2.2 CONT.

The relation between mean peak forces and net power:

Figure 3 shows the plots of the mean peak shear forces versus the net power. There is an approximately linear relationship between the mean peak shear force and net power up to a threshold value of approximately 2 N which corresponds to the critical gap. The relation deviates from linearity for the plate gaps smaller than G_C, (i.e. for higher power). Moreover, the results indicate that the fibre cutting at different rotational speeds occurs at the same shear force. However, decreasing the consistency from 3.5% to 2.5% increases the threshold value. The same trends have been found in the relation between mean peak normal force and net power.

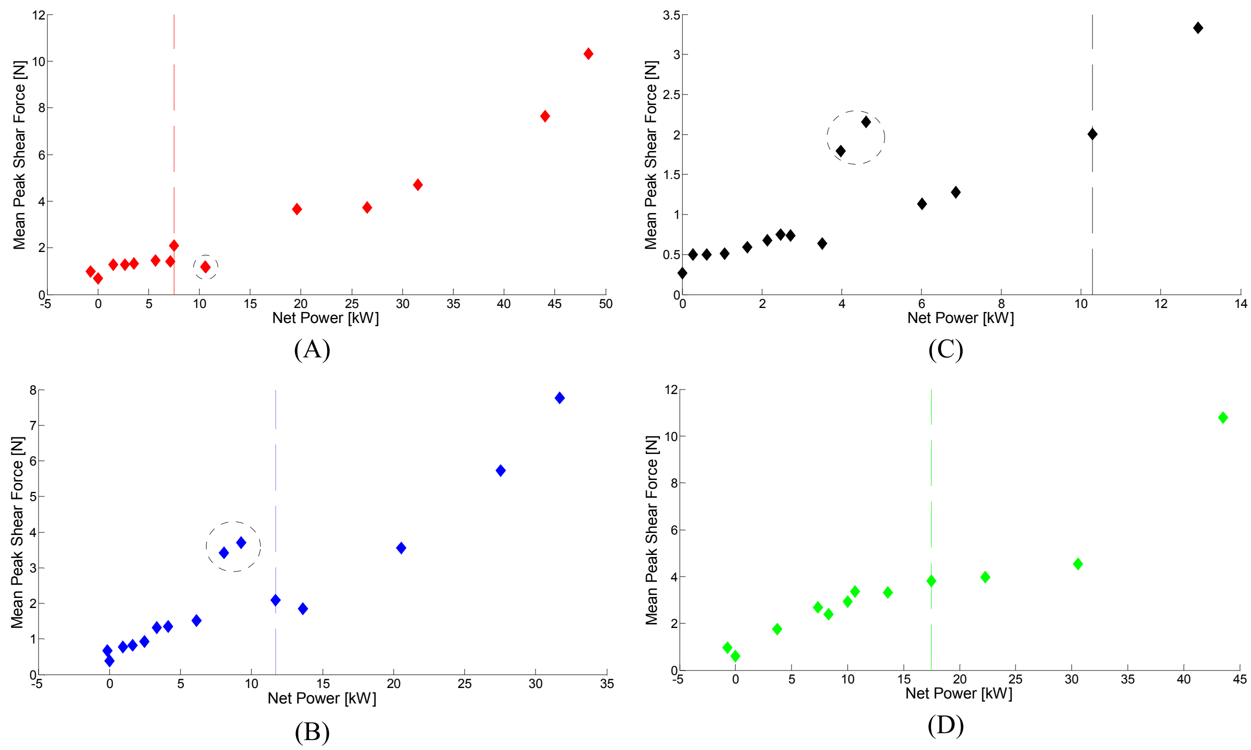


Figure 3: Mean peak shear force versus net power (A) 1200 rpm at 3.5% consistency (B) 1000 rpm at 3.5% consistency (C) 800 rpm at 3.5% consistency (D) 1200 rpm at 2.5% consistency (horizontal dashed-lines and dotted-circles indicate the critical gap and anomalous results, respectively)

Distribution of peak shear forces

The distribution of peak shear forces for three different rotational speeds at the consistency of 3.5% for two different plate gaps, before and after the critical gap, are shown in Fig. 4. As it is shown in Fig. 4A, 4B, and 4C, the distribution of peak shear forces are normal for plate gaps smaller than critical gap. However, for lower rotational speeds, the tails of the distributions are longer. For gap sizes greater than the critical gap, the distribution of peak shear forces have heavier tails and sharper peaks (Fig. 4D, 4E, and 4F). The results suggest that the shape of the distribution can be used to indicate onset detection of fibre cutting.

2.2 CONT.

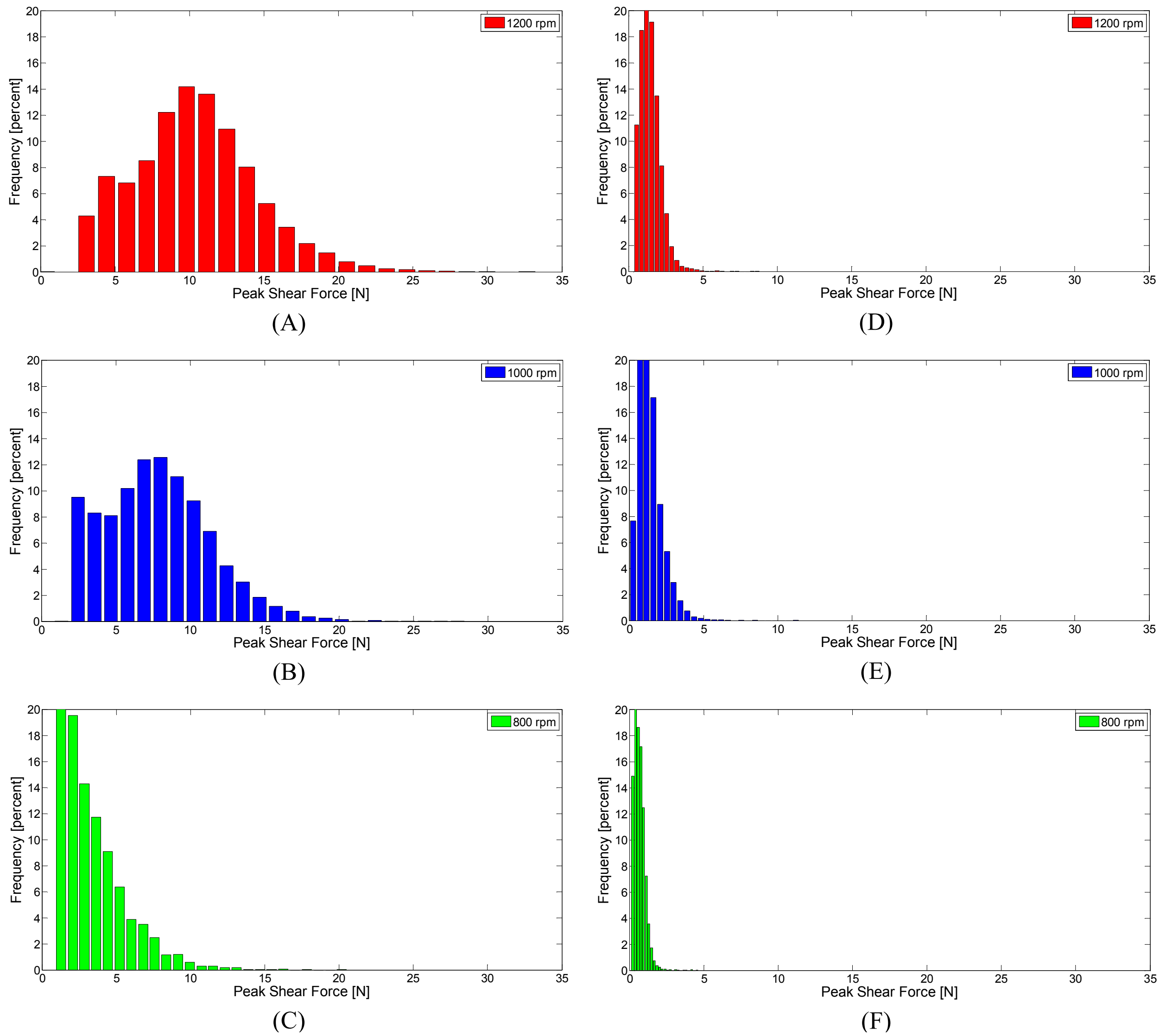


Figure 4: (A), (B), and (C) are the distributions of peak shear forces for 1200 rpm, 1000 rpm, and 800 rpm, respectively at the plate gap of approximately 0.25 mm. (D), (E), and (F) are the distributions of peak shear forces for 1200 rpm, 1000 rpm, and 800 rpm, respectively, at the plate gap of approximately 0.6 mm

Further trials are planned to explore a broader range of operating and design variables, including pulp type and consistency. In addition, by fall of 2016, the sensors will be designed and installed in a mill-scale twin-disc LC refiner at Catalyst Paper's Crofton mill, and the relationships between bar forces, refiner process variables and resulting pulp quality changes will be analyzed in detail.

References

[1] Harirforoush R., Wild P., and Olson J., "The relation between net power , gap , and forces on bars in low consistency refining", Nordic Pulp & Paper Research Journal, Vol. 31(1), 2016.

[2] Elahimehr A., Olson J., and Martinez M., "Understanding LC refining: The effect of plate pattern and refiner operation" Nordic Pulp & Paper Research Journal, Vol. 28(3), 2013.

[3] Nugroho D.D.P., "Low consistency refining of mixtures of softwood & hardwood bleached kraft pulp : effects of refining power". M.Sc. Thesis, Asian Institute of Technology, School of Environment, Resources and Development, Thailand, 2012.

RAMIN KHOIE

2.3 - ADVANCED PUMP PERFORMANCE MONITORING SYSTEM

On average, centrifugal pumps consume between 25% and 60% of the total consumed electrical energy inside process plants. Erosion inside open-impeller centrifugal pumps leads to a reduction in pump efficiency and occasional plant downtime. This project demonstra--tes a new concept for an online instrument capable of monitoring wear with the objective of improving the maintenance scheduling of centrifugal pumps and the prevention of unexpected failure through a predictive maintenance system. As part of this project, a magnetic wear sensor was designed and fabricated that allows for wear measurement while the pump is in operation. This sensor can be installed on existing centrifugal pumps and does not require any pump modifications. Wear mostly occurs on the tip of the impeller blades reducing the thickness of the impeller, which in turn, increases the gap width between the impeller and the side plate in front of the pump housing. By using a magnetic circuit with the pump and its components, wear is estimated by measuring the change in the width of the varying gap.

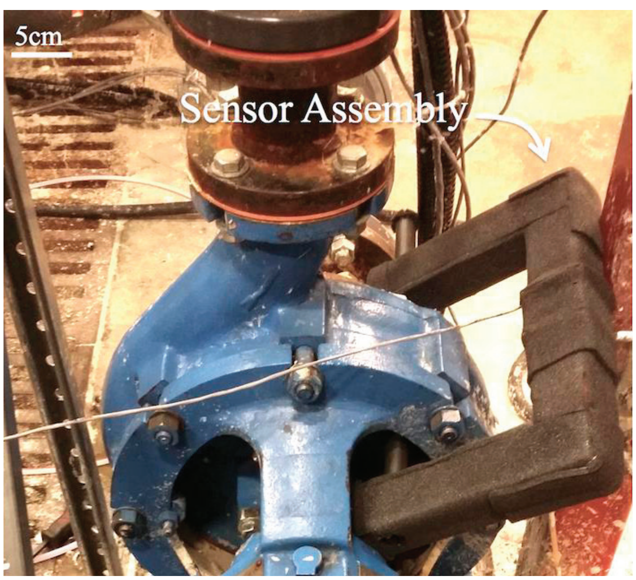


Figure 1: The sensor assembly installed on the pump.

In late 2015 and early 2016, the sensor prototype was installed on a centrifugal pump inside the Pulp and Paper Centre's pilot plant and measurements were recorded at various gap widths. The picture of the sensor on the pump is shown in Figure 1. Once the sensor is installed, measurements are taken at various pump rotational speeds to ensure the sensor is detecting the blades of the impeller. To obtain the measurements, the magnetic coil on the sensor is excited at 70 Hz and the data is collected at 50 kHz sampling frequency for a duration of one second. The speed of the pump is varied from 450 RPM to 900 RPM through the use of a VFD drive connected to the motor that runs the pump. The output signal is collected at each rotational speed and the data is transformed into its frequency domain equivalent using the fast Fourier transform algorithm. The resulting plot is shown in Figure 2. As it can be seen from the plot, the peaks correlate directly to the rotational speed of the pump. The two peaks for every rotational speed are correlated to the impeller's rotational speed and the blades' passing frequency. Since there are two blades on the pump's impeller, the blade's passing frequency is double the frequency of the impeller's rotational speed. To measure wear on the impeller blades, only the amplitude at the impeller rotational frequency is considered.

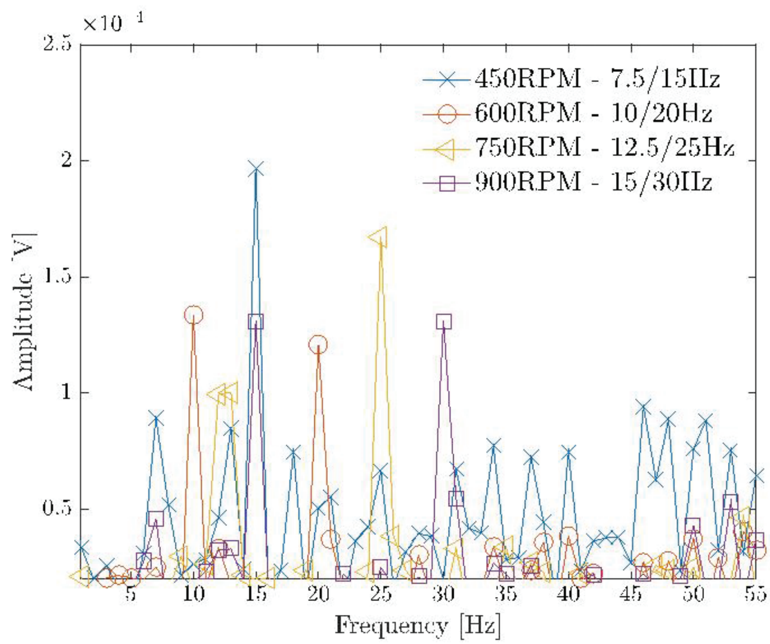


Figure 2: The amplitude spectral density of the sensor output for various pump rotational speeds.

2.3 CONT.

To calibrate the magnetic wear sensor and to observe the change in the output of the sensor as wear accumulates on the tip of the impeller blades of the centrifugal pump, the sensor needs to take measurements at various stages of the impeller's life while it undergoes erosion. Since wear occurs very slowly over a period of months or even years, an alternative method for calibrating the sensor is proposed. In this method, the gap between the impeller and the side plate is manually varied to reproduce the effect of wear on the varying gap width inside the pump. To manually vary the gap, thin ring gaskets with a thickness of 0.8 mm are inserted behind the pump housing to shift the stuffing box along with the impeller outwards. This process is repeated three times to increase the gap from an initial width of 0.381mm to a width of 2.781 mm. Each time a gasket is inserted, the sensor is installed again on the pump and measurements are collected. The location of the gaskets on the pump is shown in Figure 3.

Figure 3: The location of the ring gaskets on the centrifugal pump.

To evaluate the functionality of the sensor, the change in the sensor's output signal is examined as a function of the varying gap width inside the pump. To correlate the output of the sensor with the width of the increasing gap, the amplitude of the FFT signal at 30 Hz is plotted against the amplitude at 15 Hz for each 1 second of measurement.

The resulting scatter plot is shown in Figure 4 and the mean and standard deviations of the scatter plot are shown in Figure 5. As it can be seen from the resulting plots, the amplitude at the 15 Hz frequency is directly proportional to the varying gap width inside the pump, whereas the amplitude at the 30 Hz frequency has no correlation with the gap.

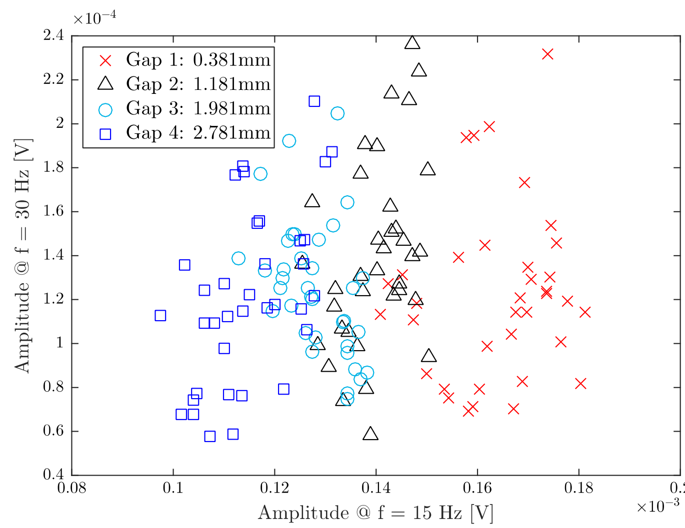


Figure 4: Scatter plot of the sensor output signal at 30 Hz versus the output signal 15 Hz for various gap widths.

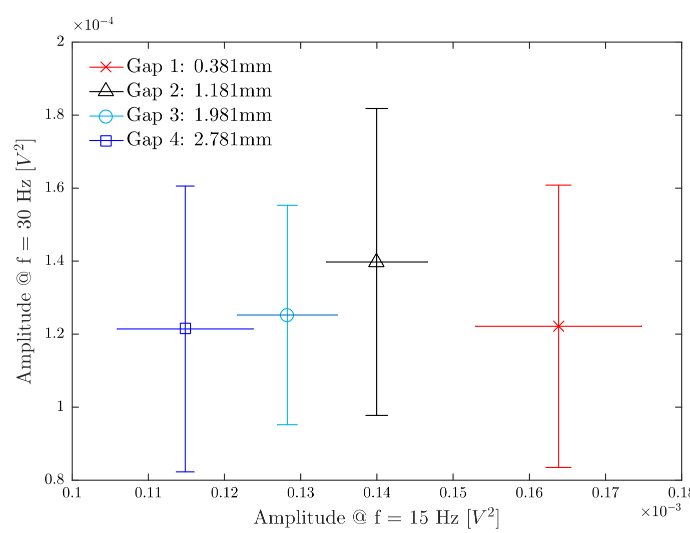


Figure 5: Mean and the standard deviation of the scatter plot for the sensor output signal at 30 Hz versus the output signal 15 Hz at various gap widths.

2.3 CONT.

Figure 6 shows the amplitude of the output signal at 15 Hz versus the magnitude of the varying gap with the error bars identified at each gap width.

Once the sensor is calibrated, the magnetic wear sensor can be used to estimate the magnitude of wear inside the centrifugal pump while the pump is in operation. To do this, data will be collected every few days for a duration of no more than one minute and the resulting data is used to estimate the change in the width of the impeller blade. To measure the magnitude of wear based on the sensor's output signal, the collected data is transformed into the frequency domain and the amplitude of the resulting signals at 15 Hz is compared against the acquired calibration curve shown in Figure 6. Based on the calibration curve, the sensor has an average sensitivity of 0.020 mV/mm and a resolution of 0.40 mm.

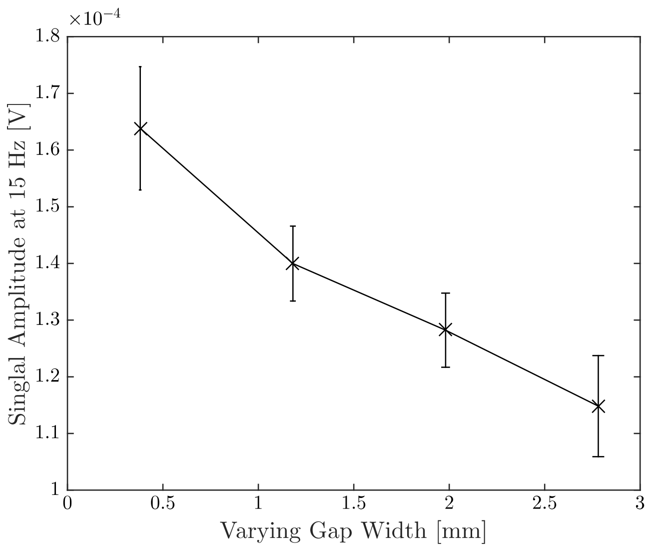


Figure 6: The mean amplitude of the sensor's output signal at 15 Hz versus the magnitude of the varying gap width. The error bar for each data point is also shown on the plot.

To conclude, in this project a live magnetic wear sensor was designed and tested in hopes that it would enable wear measurement inside centrifugal pumps. The sensor is in a form of a clamping mechanism attached to a portable instrumentation box allowing it to be installed on any operational centrifugal pump. The sensitivity and the resolution achieved by this sensor make it suitable for wear measurements of industrial pumps at mill sites.

The main limitation of this sensor is that it requires recalibration for every pump it is placed on, which could be a time consuming process. Also, the sensor is only functional for open-impeller centrifugal pumps. This class of pumps are most commonly used inside process plants for transporting slurry fluids or fluids with solid inconsistencies.

This sensor, however, introduces many other opportunities for similar wear or gap measurements. Wear measurement inside rotating machinery, for instance, where there are two parallel plates such as a pulp refiner could be achieved by this sensor. Clearance or gap measurement inside machinery is also achievable by this sensor in cases where access to the inside of the component is limited.

Ramin Khoie
M.A.Sc. '16, Mechanical Engineering.

"Being part of this unique program has given me the invaluable opportunity to work alongside industry leaders and learn firsthand about the challenges the industry is facing, and how I as an engineer can make a difference".

HANYA ETTEFAGH

3.2 - LCR PULP FOR PACKAGING PAPERS

The objective of this project is to investigate the effect of using LCR reject pulp, as well as chemical pre-treatments, on the physical and optical properties of folding boxboard. In order to achieve this, several three ply folding boxboards were made by Dynamic Sheet Former (DSF) and several tests were completed on the prepared samples. These results were discussed in the October 2015 progress report.

Completing microscopic tests

Since October 2015, more microscopic tests were completed on the previously prepared boards made with pulp that had been produced from chips pre-treated with sulphite, as well as untreated chips, and refined in an HC-LC refining sequence.

Wood chips were treated with sulphite prior to HC refining. Therefore, to investigate the sulphur content and bonding, X-ray Photoelectron Spectroscopy (XPS) test was used on each board sample. The specimens tested were made by DSF in a way that included a top and middle ply, since approximate surface depth of 5 to 10 nm can be achieved by XPS. The counts peak at 169 eV (Figure 1) of binding energy which is an indication of S-O bonding in SO_4^{2-} species, shows that the present Sulphur in the samples is in S^{6+} state.

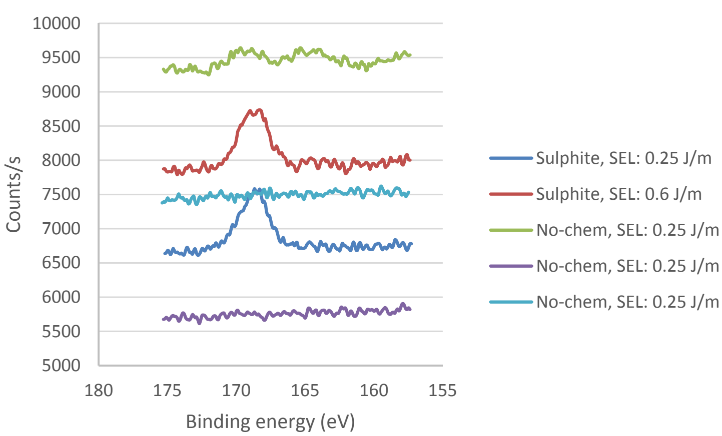


Figure 1: XPS results for sulphur content (counts/s) in the board samples at various binding energie

High-resolution XPS analyses for S element in the pretreated samples were done to have a precise chemical identification of this element, Figure 2. The S2P spectra data illustrates the presence of $S2P_{1/2}$ and $S2P_{3/2}$ that are the two spin orbit peaks related to the 2P orbital showing the presence of two electrons in $2P_{1/2}$ and four electrons in $2P_{3/2}$. According to the spin orbital coupling, the intensity ratio of $2P_{3/2}$ to $2P_{1/2}$ peak is 2:1. In addition, according to the four doublet peaks shown in Figure 2 and the XPS database the dominant S species in the sample is sulphate that indicates the conversion of sulphite, due to adding sodium sulphite, to sulphate.

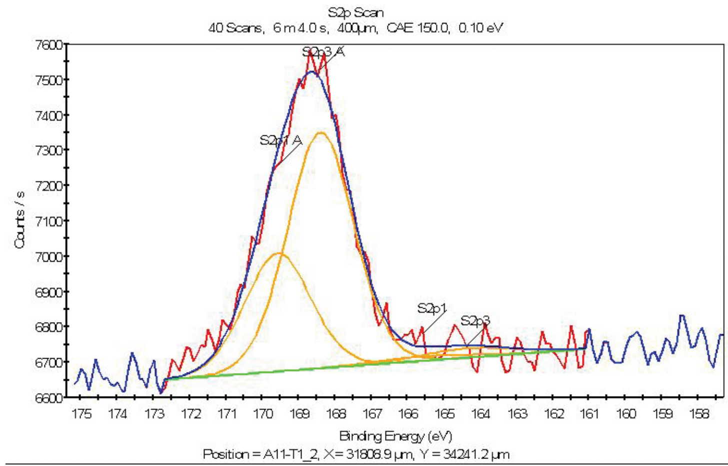


Figure 2: High resolution XPS result for the sample including sulphite

Name	*Peak BE*	*FWHM eV*	*Area (P) CPS.eV*	*Atomic %*	*Q*
S2p3	164.38	2.99	84.84	5.17	1
S2p1	165.56	3.00	42.42	0.00	0
S2p3 A	168.39	2.14	1554.02	94.83	1
S2p1 A	169.57	2.14	777.01	0.00	0

Table 1: Sulphite bonding distribution of the sulphite pre-treated sample

Conclusion of the project and future work

The most significant finding of this study was that LCR reject pulp is not only a good replacement of commercial pulps for the middle ply furnish of the folding boxboards, but also improved mechanical properties of the boards, including burst index and Scott bond, were observed when using this pulp. In addition, increasing the LCR reject pulp percentage in the middle ply furnish from 25% to 45% improves tensile, tear, burst, Scott bond, stiffness, by 9, 10, 12, 18, 20%, respectively.

As explained in the last report, using sulphite pretreatment did not significantly change the board properties and the results for this part of the project confirmed that the freeness of the middle ply furnish is the main factor influencing the board's mechanical strength. The target freeness for the this part of the project was of 400 ml, however it was not achieved for some samples and the produced pulp from HC and LC refining of chips pre-treated with sulphite and no chemical pretreatment results in freeness values of 216, and 400, 466, 366 mL. and due to limited pulp quantities it was not possible to repeat the refining trials. Hence the effect of chemical pretreatment on the board properties was not at equivalent freeness levels. It is suggested to use the specific freeness pulp and investigate the sulphite pretreatment effect.

CHUNYANG HAN

3.2 - LCR PULP FOR PACKAGING PAPERS

From recent experimental results it was observed that the freeness of low consistency refining reject pulp in the middle ply of folding boxboard (FBB), has a significant effect on the ply-bond strength of the middle ply of FBB. The ply-bond strength increases as freeness decreases, but decreasing the freeness of LCR reject pulp below 375 ml (CSF) has little further effect on the ply-bond strength of the middle ply (Fig 1) (the boxboards come from Hanya's WPI trial). This effect was attributed to the changes of fibers by LC refining. The changes include fiber deformation, internal delamination, external fibrillation, cutting fibers and fines generation. As the time and intensity increase of refining, the freeness of pulp will decrease. Meanwhile, the fibers external fibrillation will increase and bond energy between fibers also will increase.

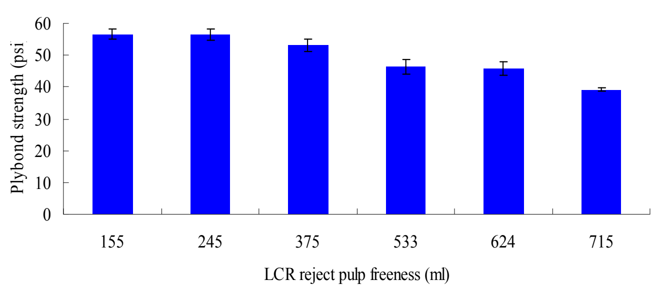


Figure 1: The effect of LCR reject pulp freeness in middle ply on ply-bond strength (boxboards produced by dynamic sheet former).

Fig.2 shows the ply-bond strength result of three ply boxboard (the boxboards come from Hanya's WPI trial, produced by dynamic sheet former). We can see that the ply-bond strength of the FBB improves as the LCR reject pulp percentage increases in the middle ply. From these results, we can observe that some FBB's mechanical properties increase, such as tensile index and ply-bond strength, with the increase percentage of LCR reject pulp. We are interested in exploring if there is one optimum LCR reject pulp percentage in middle ply that can achieve the best mechanical properties. To find out, boxboard samples with 0%, 20%, 40%, 60%, 80%, 100% LCR reject pulp percentage in the middle ply furnish of FBB were made by the hand-sheet machine. The grammage and pulps utilized were the same as with Hanya's sample.

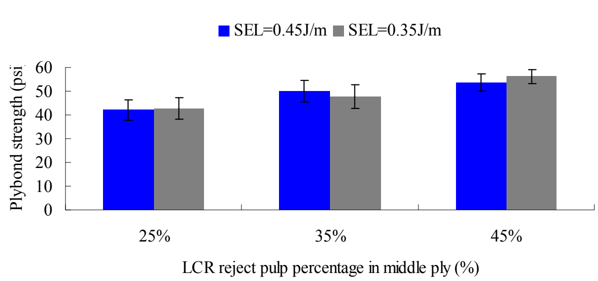


Figure 2: The effect of LCR reject pulp percentage in middle ply of FBB on ply-bond strength (boxboards produced by dynamic sheet former)

We saw a similar trend in Fig. 3. The ply-bond strength of FBB has the maximum value when the LCR reject pulp percentage in the middle ply reaches 100%. Increasing the LCR reject pulp percentage in the middle ply furnish of FBB improves the ply-bond strength and this was an expected finding. More fines generation in LC refining is possibly the main reason that the ply-bond strength was improved. Fines at the interface fill the voids and promote more intimate surface contact between plies. Increasing the LCR reject pulp percentage in middle ply means that fines also increase, so the ply-bond strength achieves maximum value when the LCR reject pulp percentage in the middle ply reaches 100%.

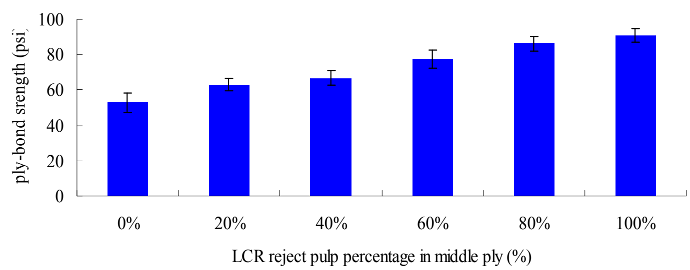


Figure 3: The effect of LCR reject pulp percentage in middle ply of FBB on ply-bond strength (boxboards produced by hand-sheet machine)

In general, we hope that the FBB has higher ply-bond strength in order to avoid delamination during printing operations or forming for packaging. This means that if we want to improve the ply-bond strength of the FBB, we can achieve this by decreasing the freeness of LCR reject pulp or increasing the LCR reject pulp percentage in the middle ply of FBB.

From Fig. 4 we observed that increasing LCR reject pulp percentage in the middle ply furnish of FBB can effectively improve the FBB's bulk. This could be due to the higher fiber length of reject pulp. Although we are doing LCR that causes more fine in the furnish, the fiber length can be higher than the other pulps, hence it decreases the density or increases bulk.

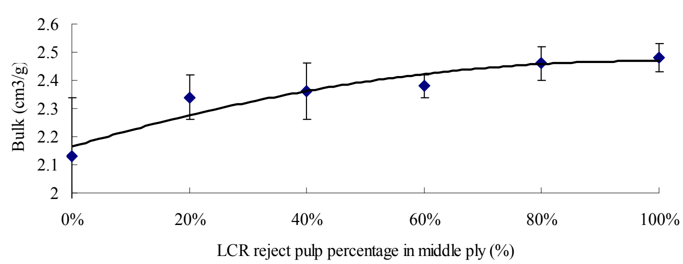


Figure 4: The effect of LCR reject pulp percentage in middle ply of FBB on bulk (boxboards produced by hand-sheet machine)

3.2 CONT.

Tensile strength and bending stiffness are two other important mechanical properties of FBB. We observed that the higher tensile strength and bending stiffness correlates to the effectiveness and strength of the packaging. In general we expect that the FBB can have higher tensile strength and bending stiffness. Literature studies have demonstrated that the increase in fiber collapse after LC refining can increase inter-fiber bonding, consequently, enhancing the tensile index. Fig.5 and Fig.6 illustrate that both the tensile index and bending stiffness are improved as the LCR reject pulp percentage increases in the middle ply furnish of FBB. The tensile index of the samples has an approximate linear increase trend with increased LCR reject pulp percentage. The difference of the total results is significant. However, results within 0-60% LCR reject pulp percentage in the middle ply furnish of FBB are not significant. This means that if the goal is to improve the FBB's tensile strength by adding LCR reject pulp, the percentage needs to exceed 60% to make a significant difference.

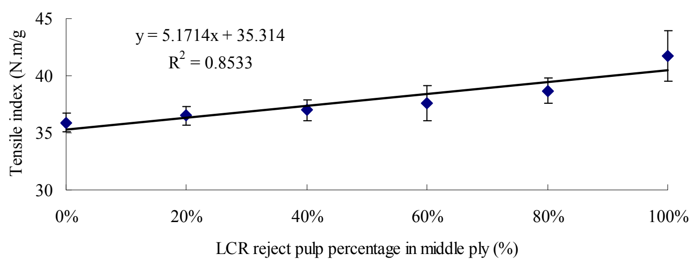


Figure 5: The effect of LCR reject pulp percentage in middle ply of FBB on tensile index (boxboards produced by hand-sheet machine)

From Fig. 6 we can also see the difference of the total bending stiffness results are quite significant, although the difference of the results with various LCR reject pulp percentage is not significant (from 20% to 100%). That means we can improve the FBB's bending stiffness by adding more than 20% LCR reject pulp in the middle ply. The bending stiffness increase is related to the bulk increase.

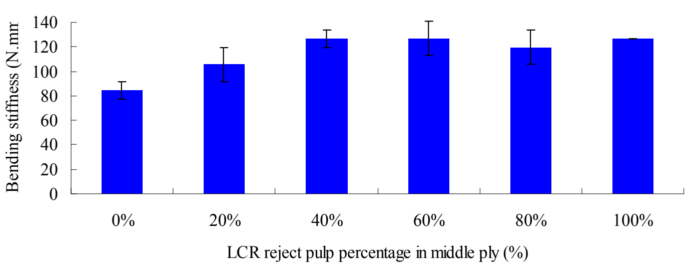


Figure 6: The effect of LCR reject pulp percentage in middle ply of FBB on bending stiffness (boxboards produced by hand-sheet machine)

The next phase of the project will evaluate the effect of fractionation and reject LC refining on folding boxboard properties. This is related to and will compliment work underway on the 2015 Andritz trials. The screened and unscreened pulp that were LC refined at low and high SEL will be used to produce the middle layer of the three-ply, folding boxboard formed using the hand-sheet maker. The top and bottom layer furnish will be a blend of hardwood and softwood kraft pulp. Top, bottom, and middle layer basis weight of all boards will be 50, 40, 120 g/m^2, respectively. Physical properties tests will include grammage, moisture content, tensile strength, ply-bond strength, stretch, elastic, tear strength, bending stiffness, thickness, bulk, and folding resistance.

NEW STAFF

The program welcomes Reanna Seifert, new Laboratory Technician. Reanna is transferring her mineral processing skills to the world of pulp testing. As a lab technician she will be assisting the ERMP staff and researchers with low consistency refining trials at UBC-PPC and performing sample testing Similar to her work in mineral exploration, she will be performing preparation work and testing of various pulp samples to determine their physical properties.

Reanna attended the University of British Columbia to study geology, earning her B.Sc. in 2013. Through UBC's Science Co-Op program she worked at several mine sites across Canada from copper mining in northern BC to iron ore in Labrador. After her studies she took a position as lab assistant at C.F. Mineral Research, a geochemistry laboratory based in Kelowna. Founded by Charles E. Fipke, discoverer of the Ekati diamond mine, C.F. Mineral Research is a world renowned mineral testing facility, specializing in diamond research. Reanna was involved in numerous projects ranging from gold to diamonds, pulverizing rocks to operating electron microprobes.

MEETINGS & PILOT PLANT TRIALS

UPCOMING:
STEERING COMMITTEE MEETING
Wednesday June 8, 2016
8:30-5:00 pm
The Fairmont Jasper Park Lodge
Jasper, Alberta

**Please contact Meaghan Miller to RSVP*

The latest Steering Committee meeting was held on November 19, 2015 at UBC. We had a strong turnout, with many industry partners attending and all researchers presenting progress updates. That week, we also took the chance to have additional meetings with Christer Sandberg of Holmen Paper and Jens Heymer of Aikawa Fiber Technologies.

The 2015 Andritz trials took place at the Andritz R&D Center in Springfield, Ohio from November 30 – December 5, 2015. The focus was on fractionation and LC refining of softwood TMP. Screening trials with various holed and slotted cylinders were conducted in order to select desired conditions. Pulp was then screened, following by LC refining of the reject pulp at low and high specific edge loads. Pulp was also mainline HC and LC refined for comparison. Prof. Olson, Meaghan Miller and Jorge Rubiano attended from UBC and are currently analysing the results. UofT and BCIT also received samples for further analysis.

Paper Excellence has visited UBC several times over the past few months to organize trials in the UBC-PPC pilot plant. James Olson, Emilia Jahangir and Meaghan Miller are working with Collin Hii and Cindy Muller on trials to investigate LC refining of mixed furnish provided by Meadow Lake Pulp.

Westcan Engineering has also visited UBC several times to work with the group on Ramin Khoie's project 2.3, "Advanced pump performance monitoring system."

We look forward to continued meetings, visits, and trials with our program partners in 2016.

PUBLICATIONS

We are pleased to report that there have been a number of publications over the last 6 months:

Report: R. P. Beatson, M. Miller, N. McIntosh, X. F. Chang, Y. Sun, and J. A. Olson, "Summary of 2014 Andritz Trials." University of British Columbia, Energy Reduction in Mechanical Pulping, October 2015.

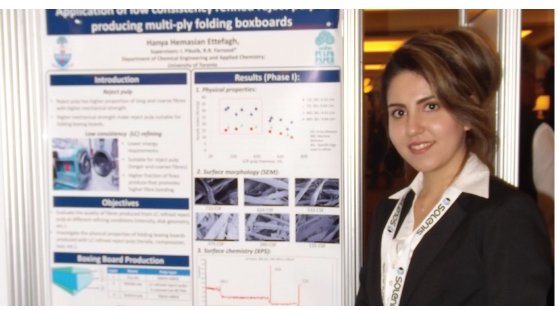
X.F. Chang, A. Luukkonen, J.A. Olson, R.P. Beatson, "Pilot-scale investigation into the effects of alkaline peroxide pre-treatments on low-consistency refining of primarily refined softwood TMP," Bioresources, Volume 11, Issue 1, page 2030, February 2016.

A. Elahimehr, J.A. Olson, D.M. Martinez, "Low consistency refining of mechanical pulp: how plate pattern and refiner operating conditions change the final properties of pulp", Nordic Pulp and Paper Journal, Volume 30, Issue 4, page 609, December 2015. (http://www.npprj.se/html/np-viewarticleabstract.asp?m=10070&mp=756)

R. Harirforoush, P. Wild, J.A. Olson, "The relation between net power, gap, and forces on bars in low consistency refining", Nordic Pulp and Paper Journal, Volume 31, Issue 1, page 071, Feb 2016. (http://www.npprj.se/html/np-viewarticleabstract.asp?m=10103&mp=759)

An updated list of all ERMP publications can be found at energyreduction.ppc.ubc.ca, and all documents can be found on the file-sharing platform: files.workspace.ubc.ca.

CONFERENCE PROCEEDINGS



R.P. Beatson, "A Mechanistic Look at Lignin Sulfonation," Pacifichem conference, Honolulu Hawaii, Dec 16, 2015.

H. Ettefagh, ""Application of low consistency refined reject pulp in producing multi-ply folding boxboards," poster presented at PAPTAC PaperWeek Canada, Montreal, Feb 2016

R. Harirforoush, J.A. Olson, P. Wild, "In-process detection of fibre cutting in low consistency refining using a bar-force sensor," presented at PAPTAC PaperWeek Canada, Montreal, Feb 2016.

Y. Sun, X.F. Chang, J.A. Olson, R.P. Beatson, "A comparison of different chemical treatments on the properties of TMP pulp followed by low-consistency refining" presented at PAPTAC PaperWeek Canada, Montreal, Feb 2016.

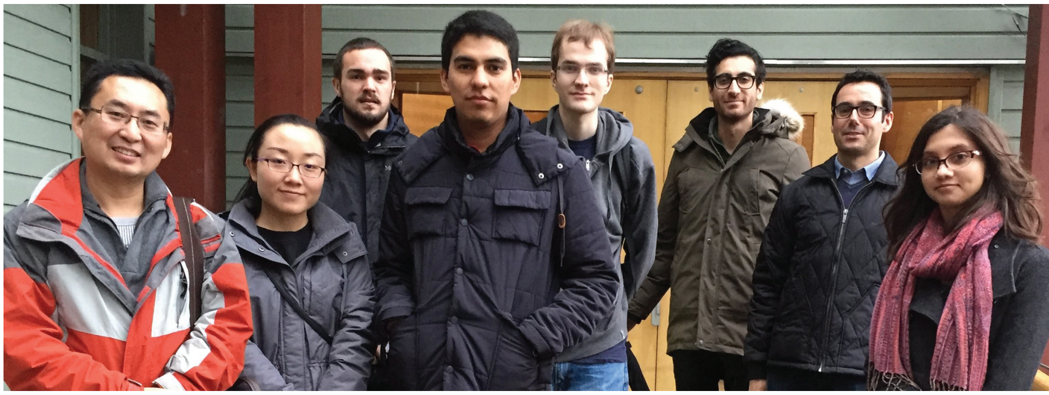
Y. Sun, X.F. Chang, J.A. Olson, R.P. Beatson, "Study on alkaline oxygen treatment of high freeness TMP pulp followed by lab-scale Low-consistency Refining," presented at PAPTAC PaperWeek Canada, Montreal, Feb 2016.

API COURSE

A three-day course sponsored by the Advanced Papermaking Initiative (API) at UBC's Pulp and Paper Centre is an annual introductory-level course suitable for current engineering students along with recently hired engineers working in BC pulp and paper mills and supporting industries. The April 2016 course again offered an LC refining component, and ERMP staff were involved in giving 20 students a refining lecture describing the principles of LC refiner operation and plate design, as well as an overview of the pilot plant setup and operation. Dr. Robert Gooding, ERMP Program Partner was also involved in teaching the 2016 course.

More information on course can be found at www.ppc.ubc.ca/api/course

TOUR OF FPINNOVATIONS



On January 12, 2016, the ERMP research group visited the facility of program partner FPInnovations located near the UBC campus. The engaging visit was organized by Ho Fan Jang, and began with a presentation of the history and current work of FPInnovations, followed by a tour of the various lab facilities including the SilviScan, light, confocal and scanning electron microscopy, pilot plant, and cellulose biomaterial lab.

FPInnovations has one of only three SilviScan instruments in the world, and the only one in North America. The SilviScan combines optical microscopy, image analysis, and x-ray technology and enables non-destructive measurements of wood and fibre properties. The group saw the large, high-tech instrument that efficiently characterizes small samples of wood (10 mm cores, which helps keep the trees intact) and heard about interesting FPI projects tracking forest inventory and monitoring wood quality.

There are several labs dedicated to microscopy, including light and confocal microscopy, where we saw how different types of paper are imaged, and we could observe distinct layers of fibres, filler, ink and paper coating. In a nearby lab we saw how samples are again imaged in a non-destructive manner through environmental scanning electron microscopy (ESEM) to identify properties such as fibre structure, and lignin and chemical content.

FPInnovations' pilot plant has a digester, for producing kraft pulp, and pilot-scale high and low consistency refiners for mechanical pulp refining. We are familiar with the LC refining pilot plant at the UBC Pulp and Paper Center, so it is always interesting to see other similar types of facilities! In an adjoining room, the group saw a demonstration of a chip sensor apparatus that can remotely monitor wood chip supply. The device measured near to infrared wavelengths to predict moisture content and density, and can allow for real-time online adjustments in a mill.

Finally, we visited the cellulose biomaterial lab, where research that uses biomaterials as polymers is being conducted, including some very interesting 3D printing techniques.

We are thankful to everyone at FPInnovations for hosting the group on a very interesting tour.

INDUSTRY NIGHT

The Master of Engineering Leadership (MEL) in Green Bio-Products is a new program jointly offered by the UBC Faculty of Applied Science, Faculty of Forestry and the Sauder School of Business, and its goal is to train the future leaders and professionals of the growing bio-products sector. To give students insight into this exciting field, Industry Nights are being arranged so experienced professionals can share their working experience with students.

The inaugural Industry Night took place on February 29th with Bill Adams, Director of Sustainability and Technology at Canfor Pulp, and also a UBC alumnus. On April 12th we were joined by Dr. Robert Gooding, VP at Aikawa Fiber Technologies. Both presentations gave insight into the organization's history, and provided valuable insight into the current state of affairs and what the future holds. The sessions were extremely successful and attended by a large group including students, faculty and staff.

If you are interested in getting involved, please contact Anna Jamroz, Communications Coordinator at anna.jamroz@ubc.ca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If you're thinking about concentrating your career in the green bio-products sector, think about the difference a year at UBC can make. Build knowledge. Cross disciplines and boundaries. Gain confidence. Master the leadership skills that will take you to the next level. Invest in yourself, and in the growing bio-economy, at UBC.
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UBC has an exceptional group of researchers who are furthering the development of biomaterials from trees, including specialty paper applications, fibre- and fibril-reinforced materials, and carbon fibres from lignin. The UBC Master of Engineering Leadership (MEL) in Green Bio-Products is designed to develop highly qualified personnel with the specialized knowledge and practical experience to assume challenging roles in the rapidly evolving lignocellulosic biomass products sector.
Unique in North America, this new degree will support graduate participation in the development of advanced technical processes, product ideation and senior project management roles.
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