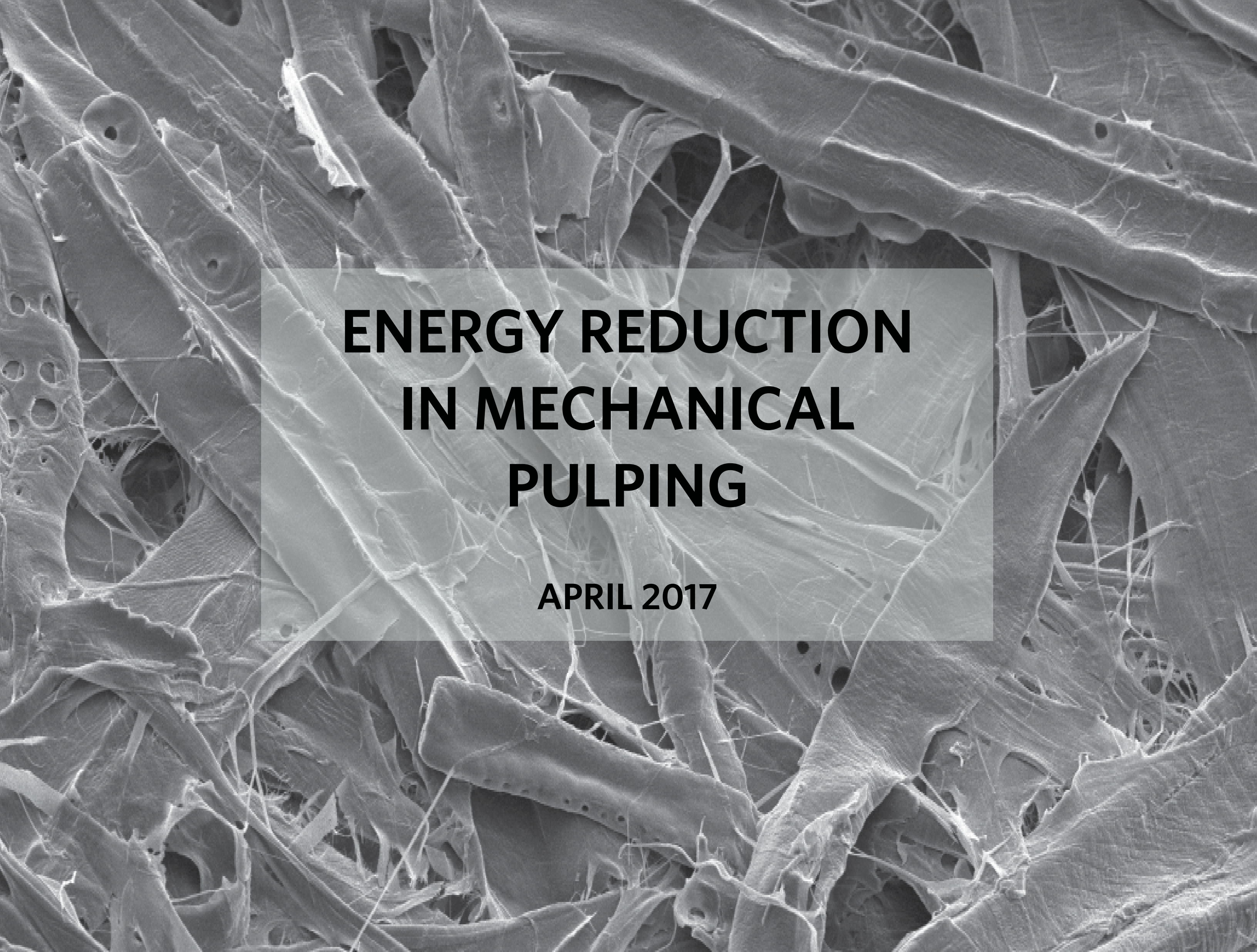


ENERGY REDUCTION IN MECHANICAL PULPING

APRIL 2017

THE UNIVERSITY OF BRITISH COLUMBIA

Welcome Message

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

As the lead of the UBC Forest BioProducts (FBP) research cluster, I am pleased to share that the recently established President's Excellence chair — which is directed at six areas in which UBC shows exemplary capacity — includes $3 million for a research chair in forest bioproducts. This will allow UBC to expand the scope of research and recruit top talent in this area. The FBP group has also applied for a Canadian Excellence Research Chair award that would provide $20 million from the federal government and UBC to bring a world-leading researcher to UBC and the FPB team. This was a highly competitive process with both internal and national competition stages, so it is quite an impressive accomplishment thus far. We are also waiting for the results of an application to the Canadian Foundation for Innovation, requesting $10 million for biomaterials research infrastructure and $4 million for biofuels research infrastructure.

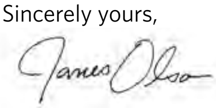
Beginning in June this year, my responsibilities expand to include a new role, Interim Dean of the Faculty of Applied Science, until the search for a new Dean is successful. I can assure you that this will not affect the research part of my life, and my commitment to the ERMP program remains particularly strong.

I am also happy to announce that our proposal to the 2016 NSERC Research Tools and Instruments (RTI) program entitled "Advanced Biomaterial Product Development Platform" was successful. We were awarded $135,800 to purchase a Dynamic Sheet Former; please see page 19 for more details. Thank you to Meaghan Miller and Emilia Jahangir for writing and submitting the proposal on behalf of the ERMP program and other UBC Pulp and Paper Centre researchers. The RTI is a competitive program so it is an exciting achievement!

In the past year, two of our ERMP alumni have started to work in the pulp and paper and allied industry. Dr. Yu Sun, Post-Doctoral Fellow from 2014 to 2017, was recently hired by Catalyst Paper's Crofton mill in the role of TMP Operations Specialist. We thank her for many excellent contributions to ERMP and look forward to working with her and supporting Catalyst. Ramin Khoie, a graduate of our Master's program in 2016, works at AutomationX Industrial Solutions as Process System Solutions Engineer and has recently initiated a project to upgrade the UBC–PPC LC refining pilot plant controls. Additionally, in December 2016, Nicholas McIntosh officially completed his MSc with ERMP and began a PhD degree at the UBC Pulp and Paper Centre in the research field of pulp dewatering.

We had a successful Steering Committee meeting in November at UBC, and we look forward to seeing all our partners at our next meeting in Whistler on June 7, 2017 — a prelude to the PACWEST conference. I invite you to read more about our recent program progress updates in the following pages. We also recently submitted our third annual Progress Report to NSERC, and look forward to continued collaboration in this current year of the program.

Sincerely yours,



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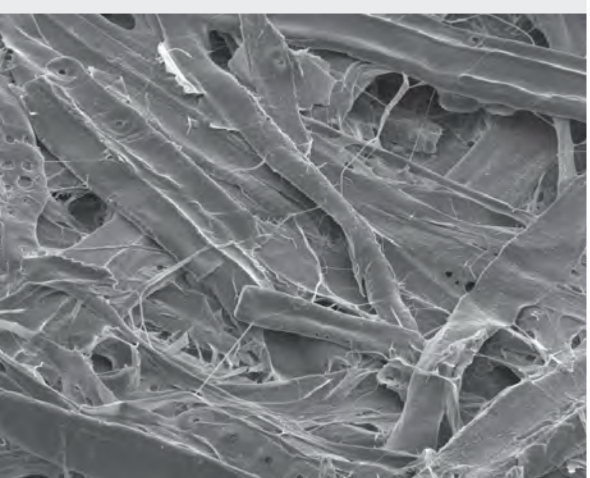

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Scanning electron microscope image of the surface of a handsheet made with addition of 14% highly refined TMP at 2242 kWh/t specific energy to high freeness primary TMP. Image at 30 degree angle to the plane of the specimen with a magnification of 300.
Photo: Emilia Jahangir

MIGUEL VILLALBA

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

The use of screw press compression in the thermomechanical pulping process allows for woodchips to be compacted into a bed. The fibres contained within the bed are defibrillated due to the compressive forces. This directly affects the exposed surface area of the cellulose fibres, which in turn reduces the amount of chemicals needed to break down the fibres. This process leads to reduction in energy consumption in the later refining steps. In spite of these benefits, screw press compression is still an energy-intensive process.

Enzyme treatment is another step taken to improve the degradation of lignin and hemicellulose. The degree of enzyme penetration in a bed of woodchips and its impact on power consumption are not yet fully understood. We are developing a research proposal for this project.

Objectives

Reducing energy consumption while maintaining the quality of pulp properties is of paramount importance in the pulp and paper industry. Ideally, pulp and paper producers want to operate the screw press at conditions that guarantee better pulp yield and properties at the lowest energy consumption.

The objectives of the project are:

- Develop a model of a screw press
- Conduct mill trials to evaluate the model
- Quantify the level of enzyme penetration on the woodchip bed

The screw press model should predict the change in shear rate caused by a change in screw operating conditions (e.g., rotational speed, power and mass input of woodchips) and geometry. It should predict the change in specific surface area or fibre damage based on the shear force applied to the woodchip bed. In other words, the model should relate the operating conditions of the screw press to changes in the woodchip bed properties. Figure 1 shows a schematic of the inputs and outputs of the model to be developed.

The model (Figure 1) will quantify the changes in shear stress rate and output flow depending on the operating conditions and geometry of the screw press. Based on that, the specific surface of the woodchip bed (Δss) can be determined. First a simple model will be developed. However, the ultimate objective of the model will be to characterize the operation of the screw press in an industrial setting as accurately as possible, with modifications as needed to match data from mill trials.

Once the model is developed, mill trials will validate the model predictions. Advanced imaging techniques are required to measure the change specific surface of the compressed wood chips. These include Cellulose Binding Domains (CBD) that can be used to measure changes in cellulose morphology due to screw compression as well as enzyme treatment. Changes in specific surface of fibre walls will be correlated to shear rate and ultimately power consumption.

Models available

An extensive literature search explored models that characterize, to a certain extent, the compression of a bed of woodchips or a similar material. A model developed by Alaqqad et al. (2011) characterizes the permeability of a bed of wood chips undergoing axial compression. The model determines the resistance to flow and its relationship to pressure and change in porosity. Another model (Hewitt et al. 2016) describes the dewatering of cellulose fibre suspension compressed axially by a piston. This model is similar to Alaqqad's model in that the solid network experiences an axial fixed rate of compression. These two models provide a good understanding of the effect of vertical compression on the permeability of the woodchip bed. However, these models do not describe the relationship of power input to the screw, shear and change in surface morphology of the compressed cellulose fibres.

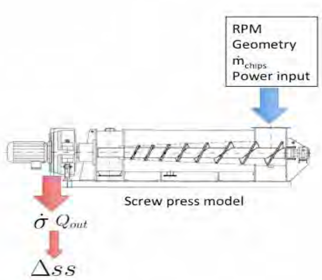

Figure 1: Overview of expected model structure

References

Alaqqad, Mohammed, Chad P. J. Bennington, and Mark D. Martinez. "The permeability of wood-chip beds: The effect of compressibility." The *Canadian Journal of Chemical Engineering* 90, no. 5 (2011): 1278–1288.

Hewitt, Duncan R., Daniel T. Paterson, Neil J. Balmforth, and Mark D. Martinez. "Dewatering of fibre suspensions by pressure filtration." *Physics of Fluids* 28, no. 6 (2016).

HARRY CHANG

1.3 OPTIMIZATION OF CHEMICAL CHARGE DISTRIBUTION THOUGHOUT THE PROCESS

The results of our previous work through laboratory experiments and pilot mill trials demonstrated that highly alkaline peroxide treatments on wood chips, high freeness thermomechanical pulp (TMP) or reject pulp can significantly reduce electrical energy consumption in refining by increasing pulp tensile strength (Chang et al. 2010, 2011, 2016; Sun et al. 2016). Compared with usual brightening in a typical peroxide bleach plant, highly alkaline peroxide treatments gave lower pulp brightness gains. We have developed a novel method of two-stage alkaline peroxide treatment that increases the brightness level achievable at high tensile strength by applying partial alkali in the first stage at high temperature and applying the remainder of the alkali dose in the second stage at low temperature. Our work on two-stage alkaline peroxide treatments has raised interest from ERMP partner mills Alberta Newsprint Company, Holmen Paper and Quesnel River Pulp. As a step towards implementation of the two-stage alkaline peroxide treatment system in the mechanical pulping processes of our partner mills, our project focuses on the optimization of treatment conditions for enhancing pulp tensile strength and maximizing brightness gain. Investigations on the two-stage alkaline peroxide treatments include the effects of treatment time and consistency in the second stage on pulp properties, and determination of optimum charge ratio of alkali to peroxide in the first stage.

Enzyme treatments in mechanical pulping processes provide another opportunity to enhance pulp properties and reduce refining energy. We are conducting initial assessment of the effects of enzyme treatments on the properties of high-freeness, primary-stage TMP.

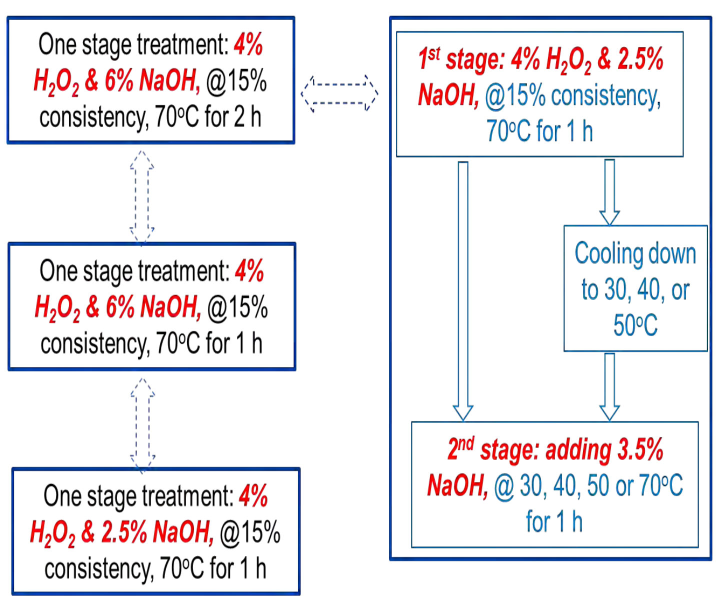

Figure 1: Method comparison of two-stage and single-stage alkaline peroxide treatments

Effects of treatment time and consistency in the second stage of two-stage alkaline peroxide treatments on pulp properties

The two-stage alkaline peroxide treatment method was developed based on our previous research findings that pulp tensile strength enhancement by alkaline peroxide treatments requires high alkalinity with the presence of peroxide. However, high alkalinity reduces pulp brightness gains due to alkaline darkening. Splitting high alkali charge in two stages and lowering treatment temperature in the second stage (Figure 1) resulted in high brightness at high tensile strength, compared to a single-stage treatment. Figure 2 shows that both tensile strength and brightness increased when second stage temperature was raised up to 50°C for a treatment using 4 per cent H_2O_2 and 6 per cent NaOH on the high-freeness softwood TMP produced during the Andritz 2014 pilot trials.

Since treatment consistency and retention time achievable in the second stage in current pulping processes vary among mills, one objective of our current project on two-stage alkaline peroxide treatment is to examine the effects of these two parameters on pulp properties. We conducted the experimental work with a high-freeness pulp from Holmen Paper. Preliminary results of our testing indicate that brightness gain continues to increase while tensile strength starts to level off after approximately 35 minutes during the second stage of the alkaline peroxide treatments using 44 per cent H_2O_2 and 6 per cent NaOH under conditions shown in Figure 1. We continue to examine the effects of consistency on pulp properties on the Holmen pulp with the same chemical charges as applied previously.

Determination of optimum charge ratio of alkali to peroxide in the first stage

To maximize brightness gain by two-stage alkaline peroxide treatments, the charge ratio of alkali/peroxide in the first stage has to be optimized since the initial pH of the bleaching liquor affects both bleaching kinetic and stoichiometry. Optimization of alkali/peroxide ratio in the first stage is ongoing on the softwood TMP produced during the Andritz 2014 trials. Different doses of NaOH to produce an initial liquor pH value of 11, 12 and 13 were charged along with 4 per cent H_2O_2, 0.1 per cent $MgSO_4$ and 3 per cent Na_2SiO_3 based on oven-dry (O. D.) weight of pulp for 30 to 240 minutes of treatment time. Handsheet properties of the treated pulps are undergoing evaluation.

PROJECT 1.3

Effects of enzyme treatments of high freeness pulp on pulp properties

Treatment of mechanical pulps with enzymes such as endoglucanases and xylanases can improve the strength properties of mechanical pulp and result in less refining required and a reduction in energy demand. The objective of the project is to assess if treatment of a coarse softwood TMP with endoglucanases or xylanases will result in improvements in strength properties of the pulp after low consistency refining thus enabling a reduction in energy consumption. Laboratory scale experiments are underway on a high-freeness pulp from Quesnel River Pulp with enzymes provided by ABEnzymes.

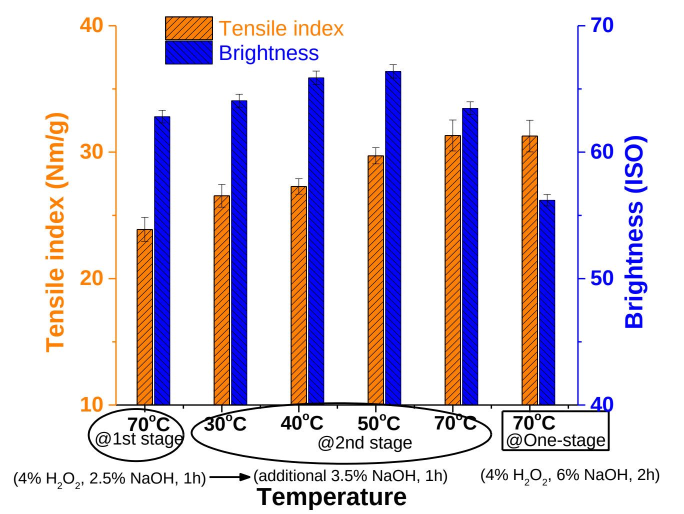

Figure 2: Temperature effects on pulp tensile strength and brightness during two-stage alkaline peroxide treatments of TMP under conditions: 4% H_2O_2, 6% NaOH, and 15% consistency.

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Chang, Xue Feng, Colin Bridges, David Vu, David Kuan, Lena Kuang, James A.Olson, Antti Luukonen and Rodger Beatson. “Saving electrical energy by alkaline peroxide treatment of TMP prior to low consistency refining”. *Journal of Pulp and Paper Science*, 36, no.36 (2010):129-134.

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JORGE RUBIANO

1.4 - OPTIMAL LOW CONSISTENCY REFINING

Comminution model

This project developed a comminution model parametrization analyzing fibre length distribution data before and after refining. A total of 15 refining trials with a variety of net powers, flow rates, plate geometries and angular velocities were analyzed. The pulps consisted of a variety of primary pulps with approximately the same initial freeness.

During the 2016 Andritz trials, two different primary pulps — from single disc and twin disc high consistency refiners — were bleached at high and low bleaching levels and then LC refined in stages. These refining data were analyzed using the comminution model parametrization to compare results previously obtained with the new refining trials.

Figure 1 shows the analysis of the 2016 Andritz refining trials as well as 15 refining trials analyzed in previous stages of this project. Interestingly, the new data yield the same exponential dependency of the cutting rate with gap. This proved the usefulness of the comminution model in analyzing fibre shortening during LC refining, where, regardless of the wide range of conditions explored, the results collapsed into a single master curve. Moreover, cutting rate did not appear to be a function of the pulp type nor of its chemical modifications for the range of gap greater than 0.5 mm. We could not establish if such behaviour would hold for smaller gaps or if a different behaviour would occur.

Power-gap relationships

A comminution model previously developed showed a strong correlation between cutting rate and fibre cutting location with gap. However, at the time of publication, it was not possible to assess a refining operation in terms of energy consumption, since the model built was expressed in terms of refining gap. Therefore, a link between gap and refining power for a variety of pulps and refining conditions is essential to find optimum refining conditions. The current focus of this project is to investigate the refining power-gap relationship as a function of pulp type, acknowledging that after the primary high consistency refining stage, pulp may be changed by screening or refining.

The total refining power was expressed as the contribution of power consumption of all bar-bar crossings. Moreover, the power consumption was due to the shear forces exerted to the pulp captured by bar-bar crossings. A mathematical expression equated to:

$$P = \omega f_s \int_{r_i}^{r_o} r dN_c(r)$$

Where ω is the angular velocity, f_S is the shear force of a bar-bar crossing and ΔN_C is the number of crossings inside a differential refining ring dr (see Figure 2). The integral term on the right-hand side of the above equation 1 is only dependent on the plate geometry and constant, as well as ω. So it is safe to say that:

$$P \sim f_s$$

The interest is to elucidate the bar-bar crossings shear forces in terms of measurable refining conditions. From here, we proposed the shear force to be the product of a friction coefficient μ (between pulp and bar-bar crossing) and the normal force f_N acting on the fibres captured by a bar-bar crossing. Literature studies demonstrate that refining power is directly affected by the inverse of gap for the same initial pulp. Therefore it is assumed that the normal force is a function of gap. However, there is little knowledge of the impact of that particular power-gap relationship for refined and screened pulps. For this reason, the fibre length l_w was will be used to indirectly account

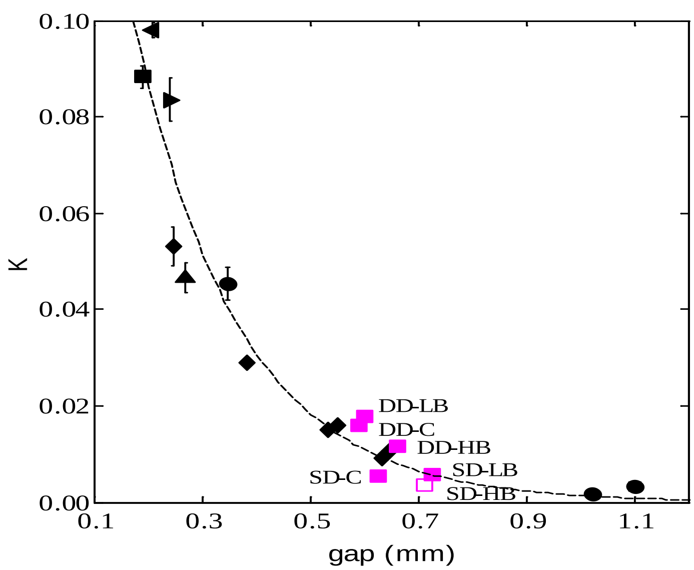


Figure 1: Estimated cutting rate (K) from the comminution model vs gap. Black markers correspond to 15 refining trials (Andritz 2015 and PPC refining trials) used to develop the comminution model parametrization in early stages of this project. The magenta square data points correspond to 6 refining trials performed at Andritz in 2016. Primary pulps were obtained from double disc (DD) and single disc (SD) high consistency refiners and bleached at a high bleach (HB) treatment and at a low bleach (LB) treatment; unbleached pulps were also refined as control (C). The results from the 2016 Andritz refining trials also show an exponential relationship with gap.

PROJECT 1.4

for pulp changes due to screening and refining. The refining power was proportional to the product of two functions as expressed in the equation:

$$P \sim \mu(l_w) f_N(gap)$$

At this stage in the project, the shape of these two functions is unknown. However, a power-law relationship for the gap and fibre length was used to fit around 200 data points (refining data). The results of the fit are shown in Figure 3a. The data fit seem to be accurate (R^2=0.89) but for gap greater than 0.8 mm there was a discrepancy between the predicted values and the measured values. The data were fitted disregarding gap greater than 0.8 mm and the results shown in Figure 3b. The fit improved substantially (R^2=0.93) and deemed safe treatment of the data since refining operations were not carried out for gap greater than 0.5 mm.

Although we obtained a good fit of the data, we could not establish a mechanistic understanding of these power-gap relationships. We proposed two generic power-law functions to describe the relationships between friction coefficient and normal force with the fibre length and gap. We continue to work on a more mechanistic model to fully understand the phenomena.

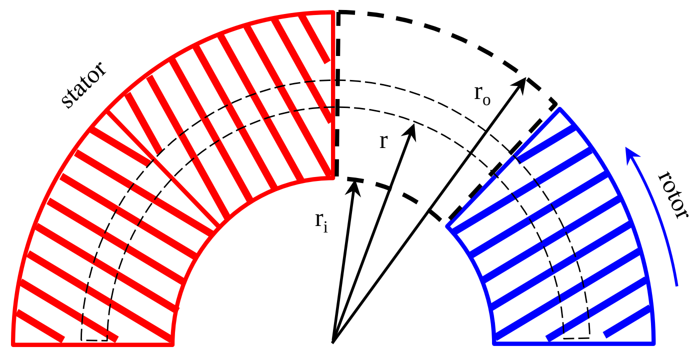


Figure 2: Cross section of a refiner showing a differential ring ***dr***

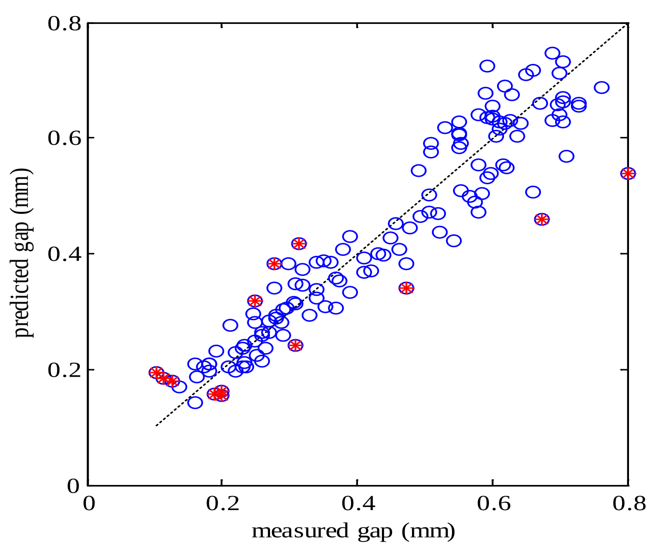


Figure 3: Refining data fit results for the power-gap relationships.
3(a) Complete data fit resulting in a R^2=0.89.

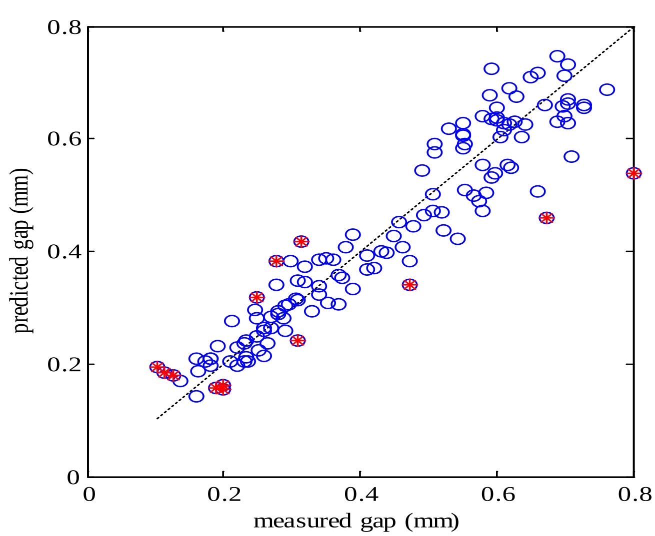


Figure 3: Refining data fit results for the power-gap relationships.
3(b): Data constrained to gap <0.8 mm resulting in a fit with R^2=0.93. Data points marked with red stars are outliers.

HUI TIAN

2.1 - OPTIMIZATION AND CONTROL OF INTEGRATED HC AND LC REFINING

In Project 2.1 we have designed a novel multi-objective economic model predictive control (m-econ MPC) algorithm for a two-stage primary and secondary high consistency (HC) refining process. From simulation results, we have demonstrated that by using the proposed m-econ MPC controller, significant reduction in specific energy consumed by the MP process can be achieved in comparison with the traditional tracking MPC control technique.

We use a general form of Wiener-type state space model to describe the complex multi-input-multi-output (MIMO) non-linear mechanical pulping (MP) process. In this model, we assume that all the state variables and the system outputs were measurable and available for the controller design purpose. However, for the MP process the state variables were rarely available directly from process measurements, and the states typically needed to be inferred from secondary process measurements or a measurable subset of the state. Moreover, due to the lack of fast and efficient online pulp property sensors, a mechanical pulp mill prepares and tests handsheets to determine pulp properties. The use of handsheets requires skilled technicians and introduces a significant lag before the data can be derived. Our project focuses on designing an online state estimator for the unmeasurable state variables and the pulp properties to counter the inherent challenges in using manual property measurement using handsheets.

One general approach for constructing a state estimator is to model the state as a stochastic process. The probability theory is a natural framework to make predictions under uncertainties. Our project uses the well-developed moving horizon estimator (MHE), one of the most popular estimation in the industry. MHE is an optimization-based strategy for state estimation that explicitly allows for non-linear models and inequality constraints. The basic strategy of MHE is to estimate the state using a moving and fixed size window of data. When we estimate the state at the next time index, we add the new measurement to the data window and remove the oldest measurement.

The best estimate of the state at time given the measurements $\{y_k\}_{k=0}^{N-1}$ can be obtained by solving the following optimization problem,

$$\Theta_N^* = \min_{x_{N-M},\{w_k\}_{k=N-M}^{N-1}} \Theta_N(x_{N-M},\{w_k\}_{k=N-M}^{N-1})$$

subject to the constraints

$$\{x_k\}_{k=N-M}^{N} \in \mathbb{X}^{M+1}, \qquad \{w_k\}_{k=N-M}^{N-1} \in \mathbb{W}^{M},$$

where the objective function is of the form:

$$\Theta_N(x_{N-M},\{w_k\}_{k=N-M}^{N-1}) \triangleq \sum_{k=N-M}^{N-1} L(w_k,v_k) + \Gamma_{N-M}(x_{N-M})$$

In the MHE formulation, $\{w_k, v_k\}$ represent the randomness of the state transition from x_k to x_{k+1} and the measurement noise. $(L(w_k, v_k))$ is the stage cost. $\Gamma(x_{N-M})$ is the arriving cost summarizing the affect of past data on the current state variable.

Our project status is completion of the preliminary MHE design for the two-state HC MP process. We used a general form of Wiener-type model to describe the two-stage HC MP model. In this process model, the production rate, motor loads and consistencies for both primary and secondary refiners were chosen as the discretized differential state variables while the pulp properties after each refiner were treated as the algebraic state variables. The chip-transfer screw speed, plate gap and dilution water flow rates of each refiner were taken as the manipulated variables. For the HC refining process, the consistency of the pulp in the refining zone plays an essential role in determining the final properties of the pulp. However, due to the high rotational speed of the HC refiner, the consistency of the pulp in the refining is difficult to be measured. In the simulation, we proposed to design the MHE estimator and infer the consistency by using the measurable states — the production rate, motor loads for both primary and secondary refiners.

We ran the closed-loop simulation for a two-stage HC refining process with m-econ MPC controller for 160 sampling time to obtain the history control loop data that comprised noisy measurements of the production rate and motor loads of both primary and secondary refiners. We assume that the measurements were with Gaussian noise and that the variance was 0.01. In the simulation, the estimation horizon was chosen to be 5 sampling time. The simulation addressed computational issues using the nonlinear MP process model built in AMPL (A Mathematical Programming Language) and resolved the non-linear optimization using IPOPT (Interior Point Optimizer).

The simulation results shown in Figures 1 to 5 provide a good estimation for the noisy measurements of the production rate, and motor loads for both primary and secondary refiners (shown in Figures 1, 2 and 3 respectively). Figures 4 and 5 illustrate the estimation results for the unmeasurable states of the consistency for the primary and secondary HC refiners.

PROJECT 2.1

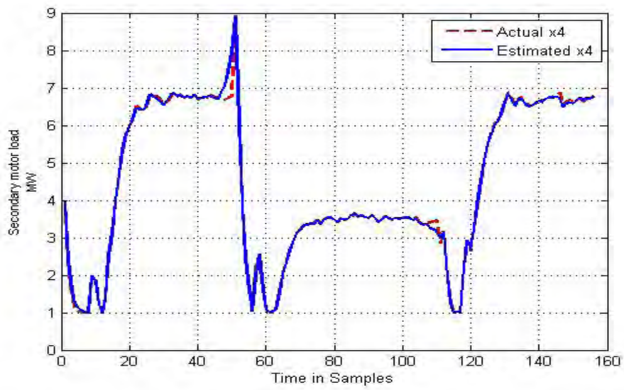


Figure 1: Estimation results for the production rate by using MHE.

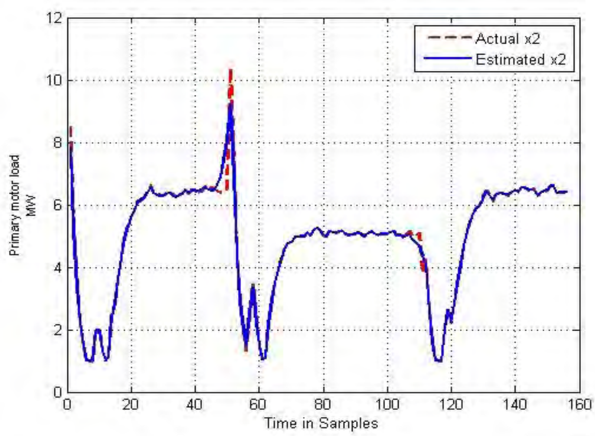


Figure 2: Estimation results for primary motor load by using MHE.

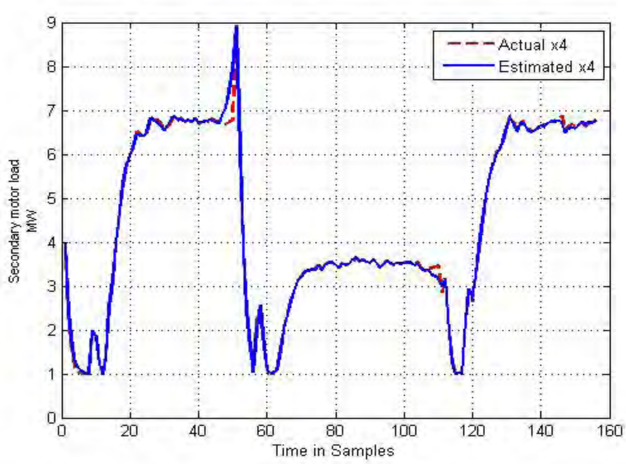


Figure 3: Estimation results for the seconday motor load by using MHE.

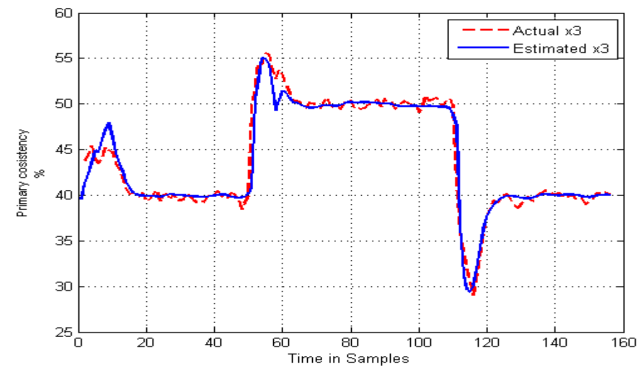


Figure 4: Estimation results for the primary consistency by using MHE.

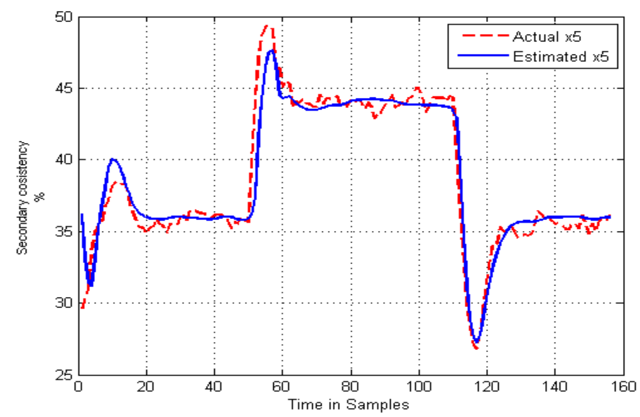


Figure 5: Estimation results for the secondary consistency by using MHE.

Since our project addresses control and state estimations separately, our next goal is to integrate the control and MHE estimator into one closed loop. The final control-estimation loop for the MP process is shown in Figure 6.

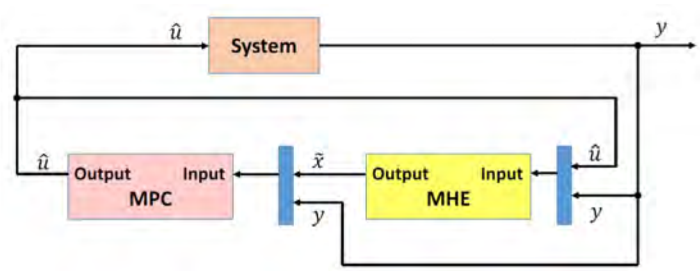


Figure 6: Graphical depiction of the integrated MPC and MHE for MP process.

REZA HARIRFOROUSH

2.2: LOW CONSISTENCY REFINER BAR FORCE SENSOR BASED CONTROL STRATEGIES

Low consistency (LC) refining of mechanical pulp has been shown to be more energy efficient than conventional high consistency (HC) refining. However, the degradation of mechanical properties due to fibre cutting at high refining energies has limited the widespread adoption of LC refining. Conventional strategies to avoid fibre cutting are based on post-refining measurement of pulp properties and, typically, do not enable rapid adjustment of refiner operation in response to the onset of fibre cutting. The objective of this study is to detect the onset of fibre cutting by using custom-designed piezoelectric force sensors that measure shear and normal forces applied to pulp fibres by the refiner bars.

Pilot-scale trials were performed using an AIKAWA 16 inch single-disc LC refiner at the Pulp and Paper Centre at the University of British Columbia. Trials were run using different pulp furnishes — Catalyst hemlock/balsam softwood TMP, QRP SPF (spruce, pine, fir) softwood high freeness, NBSK (northern bleached softwood kraft), and Millar Western hardwood TMP — at 3.5 per cent consistency for two different rotational speeds (i.e. 1200 and 1400 rpm) and a wide range of plate gaps. The pulp was sampled at regular intervals and the length-weighted fibre length (L_w) was determined for each sample. The data recorded from the sensor were analyzed to determine the distribution of the peak normal and shear forces. The results show that the indications of the onset of fibre cutting previously found (Harirforoush et al. 2017) can be extended to different pulp furnishes and operating conditions. In addition, more clearly distinct transitions are observed in the plot of power of normal and shear forces versus plate gap which correspond to the onset of fibre cutting. These transitions, described below, are believed to be caused by a fundamental transition in the fibre-bar interaction.

Power of forces

The total power of a signal is defined as the sum of absolute squares of time-domain samples divided by the signal length or the square of the RMS (Root-Mean-Square) value. As shown in Figure 1a–d, distinct transitions (highlighted by dashed lines that correspond to the transition seen in the plot of L_w versus the inverse of plate gap) occur in the plot of power of normal forces versus plate gap which correspond to the onset of fibre cutting. The transition is less definitive for NBSK, Figure 1c. For this pulp, flow rate was observed to be unstable, which may reflect unstable conditions in the refiner and may also be the cause of anomalous data.

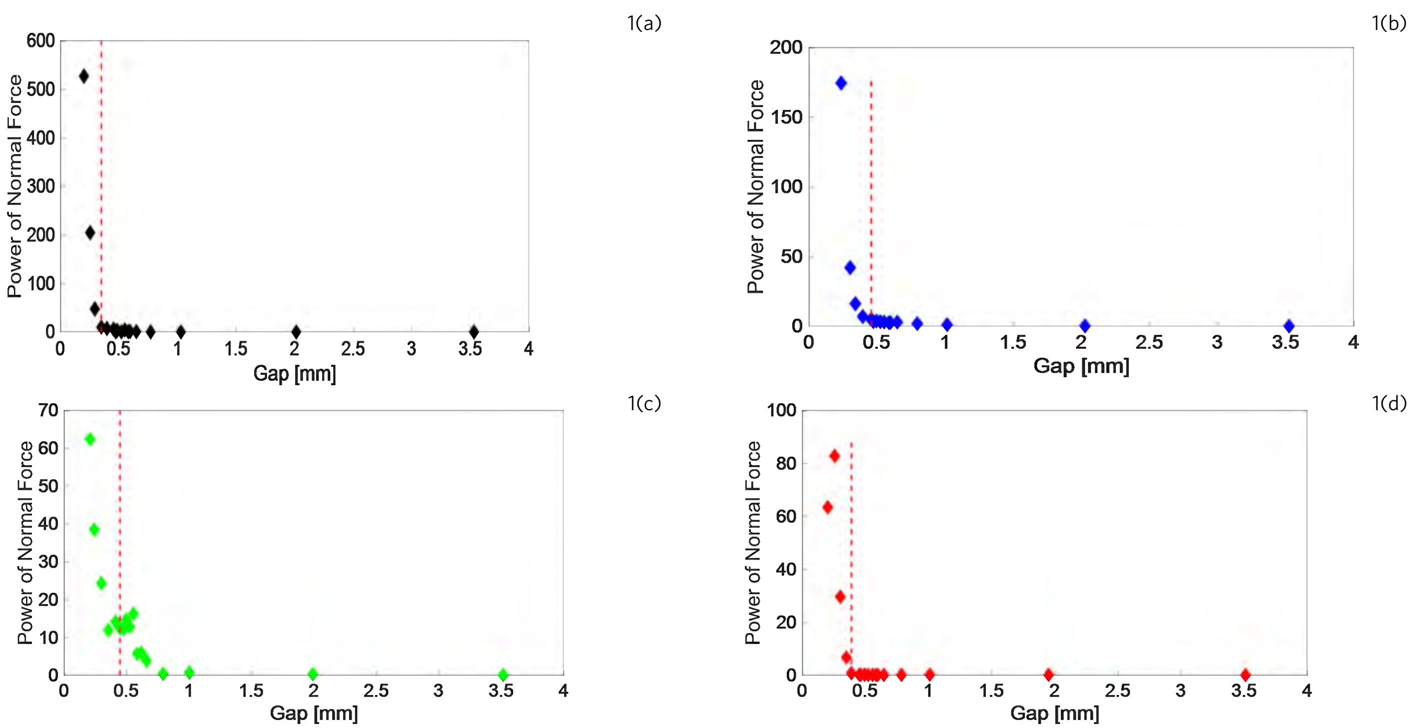


Figure 1: Power of normal force versus plate gap for pulp furnishes: (a) Catalyst hemlock/balsam softwood TMP , (b) QRP SPF softwood high freeness, (c) NBSK, and (d) Millar Western hardwood TMP.

PROJECT 2.2

Mean peak forces

Figure 2a and b show that L_w remains relatively unchanged as mean peak normal force increases up to a threshold value that corresponds to the critical gap (highlighted by dashed lines). The L_w value decreases in an approximately linear manner beyond the critical gap threshold. A similar trend was noted in the relationship between L_w and mean peak shear forces, Figure 2c and d. At critical gaps, the mean peak shear forces are relatively constant for different pulp furnishes while the mean peak normal forces for hardwood pulp are much lower than for softwood pulp.

Weibull scale parameter of peak force distribution

A two-parameter Weibull function is fit to the distribution of peak forces. The scale parameter, which is one of the key parameters of the Weibull function, is calculated and plotted as a function of plate gap. Figure 3a and b show that as the plate gap is decreased, the scale parameter remains relatively constant up to a threshold value. The threshold (highlighted by dashed line) corresponds to the transition seen in the plot of L_w versus the inverse of plate gap. This transition is in agreement with the onset of the fibre cutting.

Mean coefficient of friction

The mean coefficient of friction (i.e., peak shear force divide by peak normal force) decreases as the plate gap is reduced, as shown in Figure 4a and b. More likely, the change in fibre properties may have been due to a change in forces on the fibres and perhaps an increase in compression versus shear forces on the fibres and thus more internal fibre fibrillation.

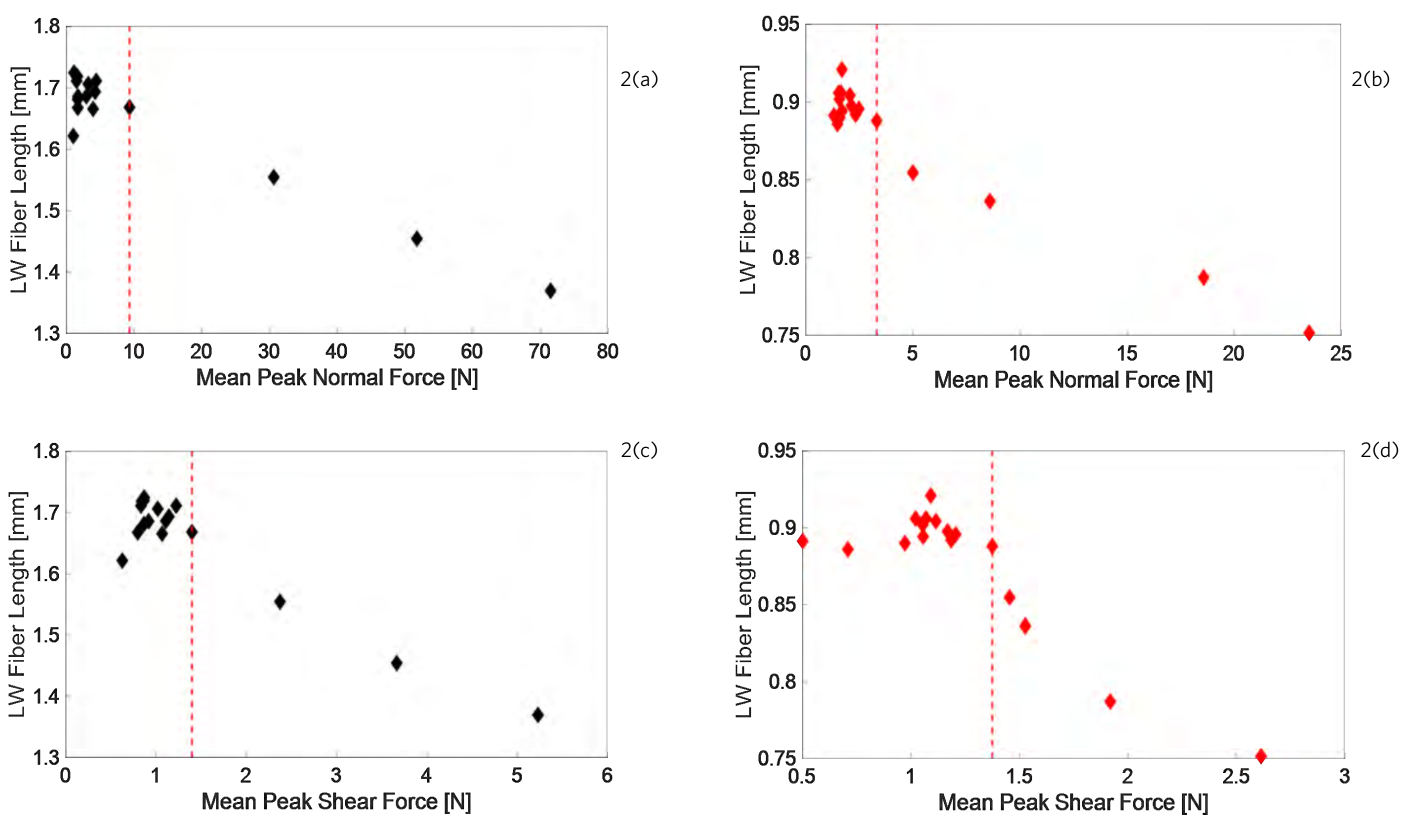


Figure 2: L_w versus mean peak normal force for (a) Catalyst hemlock/balsam softwood TMP, and (b) Millar Western hardwood TMP, and L_w versus mean peak shear force for (c) Catalyst hemlock/balsam softwood TMP, and (d) Millar Western hardwood TMP.

PROJECT 2.2

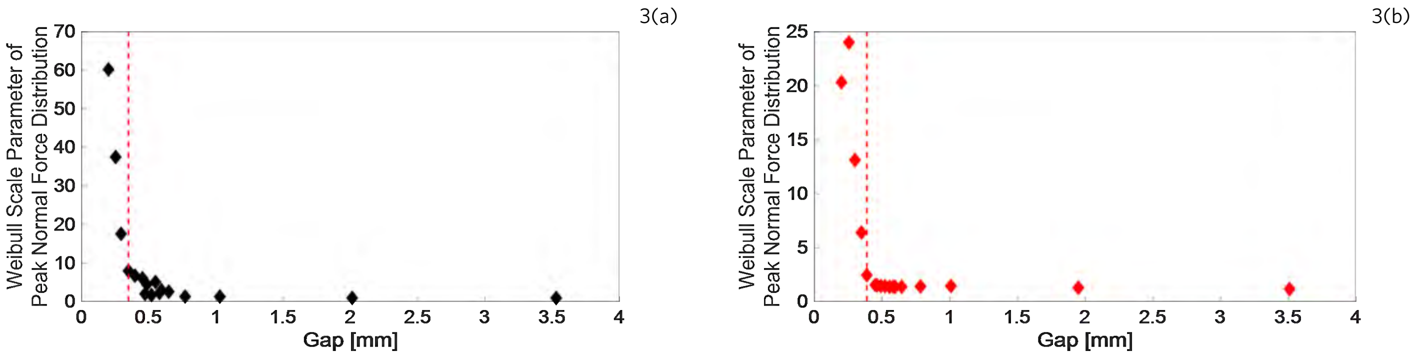


Figure 3: The Weibull scale parameter of peak normal force distribution versus plate gap for (a) Catalyst hemlock/balsam softwood TMP, and (b) Millar Western hardwood TMP.

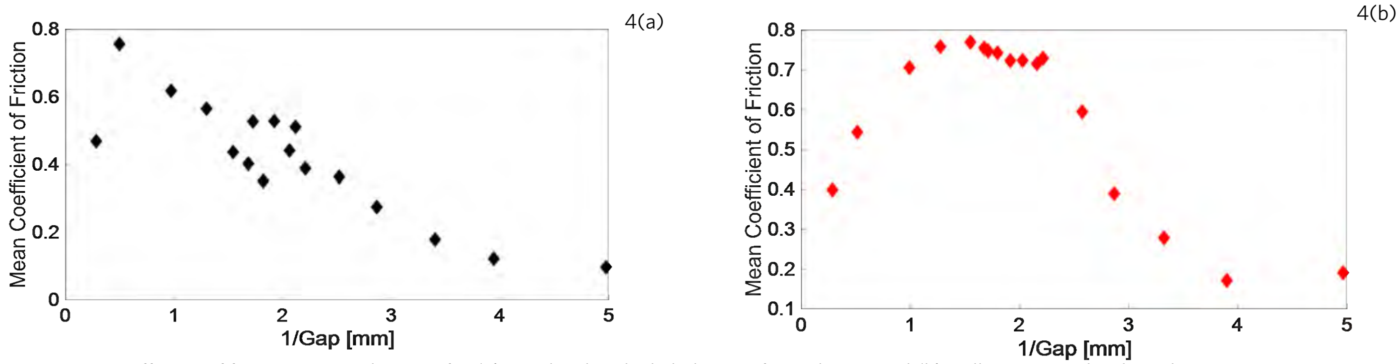


Figure 4: Mean coefficient of friction versus plate gap for (a) Catalyst hemlock/balsam softwood TMP, and (b) Millar Western hardwood TMP.

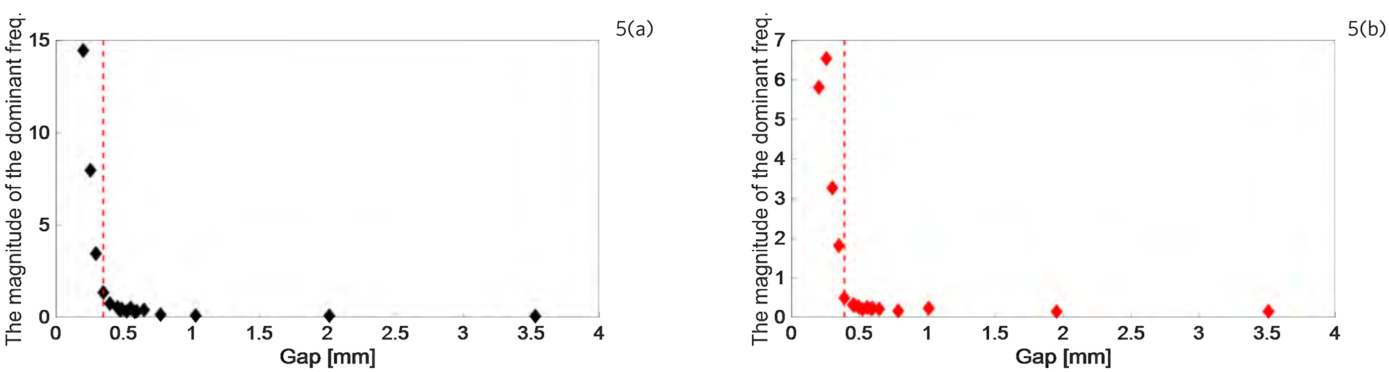


Figure 5: The magnitude of the frequency corresponds to the passage of equivalent edges in adjacent three-bar clusters versus the plate gap for (a) Catalyst hemlock/balsam softwood TMP, and (b) Millar Western hardwood TMP.

References

Harirforoush, Reza, James A. Olson, and Peter Wild. "In-Process Detection of Fiber Cutting in Low Consistency Refining Based on Measurement of Forces on Refiner Bars" *TAPPI Journal* 16 no. 4 (2017): 189–99.

TARANEH KORDI

3.2: LOW CONSISTENCY REFINER PULP FOR PACKAGING INDUSTRIES

The project focuses on the application of screening in low consistency (LC) refining. This application reduces refining energy by fractionating primary high consistency refined (HCR) pulp, and then LC refining (LCR) only the long fibre fractions (reject pulp). The objective of this project is to examine the effect of using LCR reject pulp and various screen cylinder designs on the physical and mechanical properties of folding boxboard (FBB). For this purpose, several 3-ply folding boxboards were prepared with different middle plies using a hand-sheet maker. Top, bottom, and middle layer basis weights of all samples were 50, 40, 120 g/m^2, respectively. Quesnel River Pulp provided SPF (spruce, pine, fir) pulp at about 600 ml CSF. The pulp was shipped to the Andritz R&D Center in Springfield, Ohio. The HC refined pulp was fractionated using three different screen cylinders with 0.8 mm, 1.0 mm, and 1.5 mm diameter holes. Each screened pulp was LC refined at two intensities (specific edge load), achieved by changing refiner power. Unscreened pulp was both HC and LC refined as control.

Physical Properties Results

Several tests were conducted on the 3-ply folding boxboards which included tensile strength, ply-bond strength and bending stiffness. Middle-ply was produced from the combination of reject and accept pulp with a specific ratio according to the reject ratio obtained after screening. The middle-ply furnish freeness was measured in our lab at University of Toronto. The summary of physical properties and bulk of samples, as variables of screen cylinders and middle ply furnish freeness, was shown and compared to control samples in Figure 1. The control pulp samples prepared by HC and LC refining are denoted as HCR-HCR and HCR-LCR in Figure 1. The properties were compared at the target freeness of 420 ml CSF.

Results, Discussion and Conclusion

Screening prior to LC refining decreased the tensile strength; however, at the middle ply furnish freeness of 420 ml, the tensile index of samples from 1.0 and 1.5 mm hole diameter screen baskets approached that of no screening HCR-LCR samples (Figure 1a). Ply-bond strength increased as the middle-ply furnish freeness decreased (i.e., SRE increased). Maximum ply-bond strength was observed for no screening HCR-LCR and 0.8 mm hole diameter screen basket which had lower freeness. However, at the target middle ply furnish freeness of 420 ml, interpolated data showed the highest ply-bond strength for 1.0 mm hole diameter (Figure 1b). Bending stiffness of samples decreased by

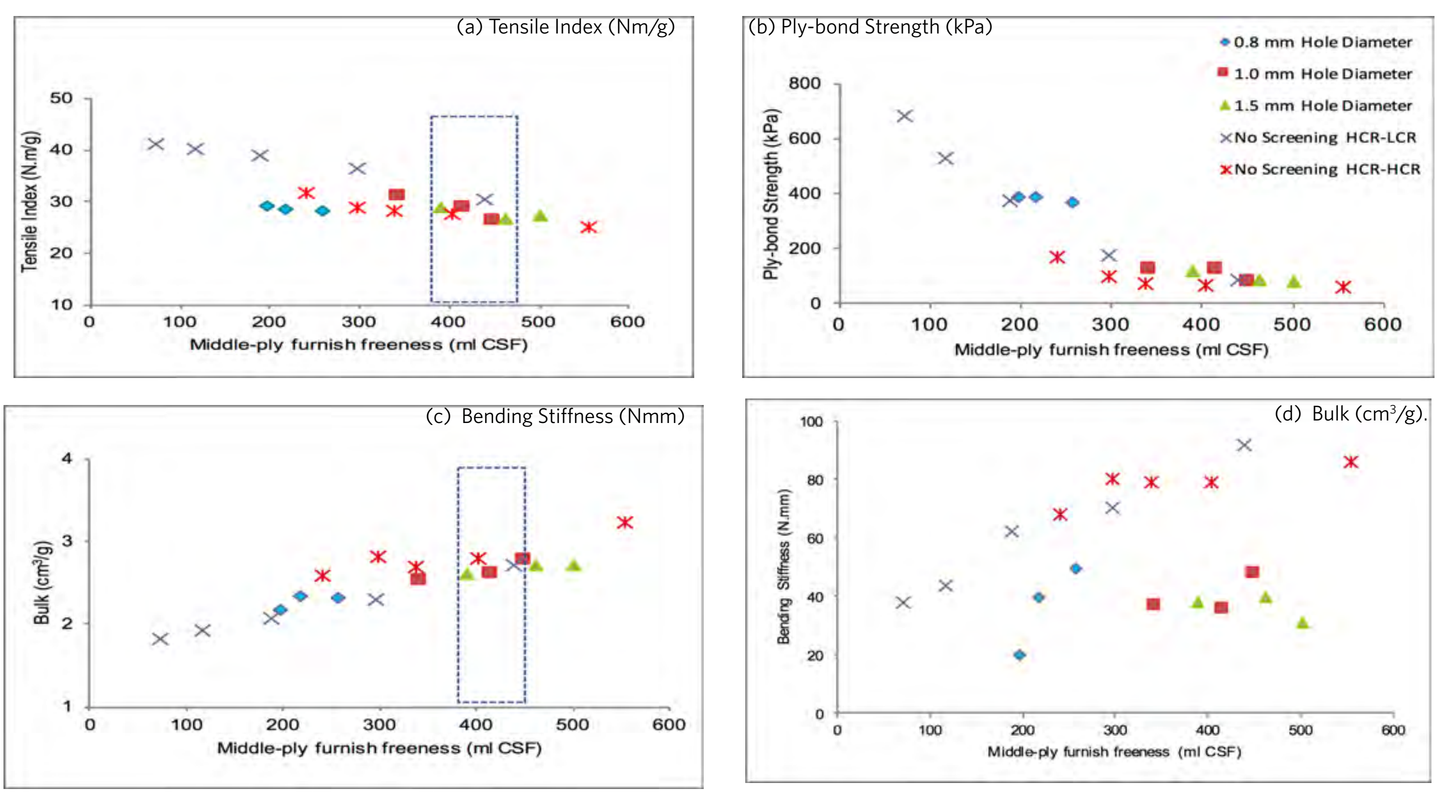


Figure 1: The effect of various screen baskets and pulp freeness at SEL 0.5 (J/m) used in middle ply. For screening samples, freeness of middle-ply of FBB furnish was measured at University of Toronto

PROJECT 3.2

screening and at the middle-ply furnish freeness of 420 ml, bending stiffness of FBB samples containing screened pulps was less than 50 per cent of those of unscreened pulp samples (Figure 1c). Moreover, the estimated bulk samples containing screened and unscreened pulp was in range of 2.7 ± 0.1 (Figure 1d).

Future Projects

The next phase of the project aims to study the effect of refining intensity by comparing results obtained for SEL of 0.5 J/m with the results of SEL 0.25 J/m. The project will see further tests conducted including tear index, moisture content, and folding resistance. Results will be studied in terms of energy consumption and fibre properties, notably fibre length, width, coarseness, and relative bonded area.

BAHAR SOLTANMOHAMMADI

3.2: LOW CONSISTENCY REFINER PULP FOR PACKAGING INDUSTRIES

Flexible packaging papers (FPP) are considered green alternatives to plastics due to their end-use performance, low cost, and environmental benefits. In addition to good strength, printability and friction properties, FPP offer tunable porosity that could be an important factor for controlling gas, oil, and water permeability rates.

The aim of this project is to explore the use of low consistency refined pulps (LCR) in FPP production. Various single ply samples containing several blends of LCR mechanical pulps (with various freeness values) and kraft pulp for sack papers will be prepared using standard handsheet making process (Figure 1) and will be tested for tensile strength and tear strength. In addition, porosity, gas permeability, wettability, and water and oil penetration will be also measured.

We will prepare control samples containing 100 percent kraft pulp and compare the results to those obtained from FPP samples containing LCR-kraft blend furnish. The basis weights of all samples will be 80 g/m^2. Based on the results, we will determine the optimum amount of LCR content in the furnish and establish various strategies to enhance the performance of LCR-containing sack papers.

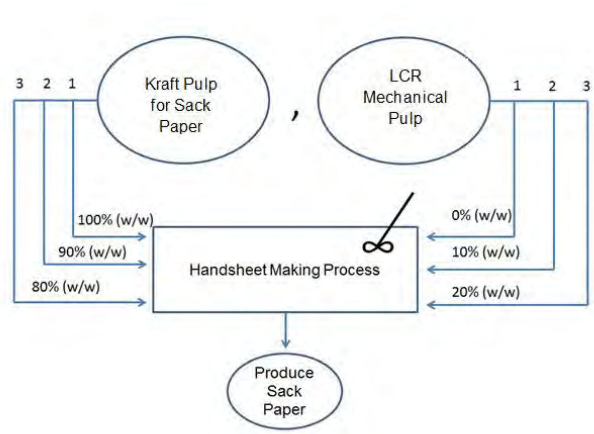


Figure 1: The experimental procedure

EMILIA JAHANGIR

LCR HIGH ENERGY TMP MICRO-FIBRE FOR HIGH BULK, HIGH TEAR AND HIGH TENSILE MECHANICAL PULP

Low consistency refining of thermo-mechanical pulp provides an energy efficient alternative to high consistency refining for pulp property development. However, the benefit of LC refining is often limited by excessive fibre shortening, lower tear strength and reduction of bulk caused by the refining process. In this study, high energy micro-fibres were produced by low consistency refining of high freeness TMP and kraft pulp to investigate their reinforcement potential in TMP based paper.

Trials were carried out at Pulp and Paper Centre's pilot facility using an Aikawa single disc low consistency refiner with 16" overhung plates and continuous flow recirculation loop. High freeness primary TMP was LC refined to different energy levels to provide a basis for mechanical and optical property development. Composite samples were made by the addition of highly refined (HR) micro-fibre to unrefined primary TMP in ratios such that the composites corresponded to the specific refining energies of the LC refined pulp samples. Samples tested were grouped as: a) conventional LC refined TMP b) high freeness primary TMP reinforced with highly refined TMP at 2242 kWh/t c) primary TMP mixed with highly refined TMP at 1567 kWh/t, and d) primary TMP mixed with highly refined kraft at 2430 kWh/t.

The study revealed that the composites made with highly refined TMP at both 2242 kWh/t and 1556 kWh/t specific energies yield tensile strength similar to that of LC refined TMP at corresponding energies. As well, highly refined TMP added to unrefined primary TMP increased tear index, preserved bulk and improved freeness by a significant margin. The addition of highly refined kraft to primary TMP produced composites with highest tensile and tear strength in this study.

This investigation proposes an alternative cost effective solution to develop TMP pulp properties by limiting the extent of second stage refining and using highly refined fibres as TMP reinforcement. The high tear–high bulk open construction of the composite sheets is likely to benefit the packaging and tissue grades. Further investigation is essential to evaluate the potential of these high strength composites.

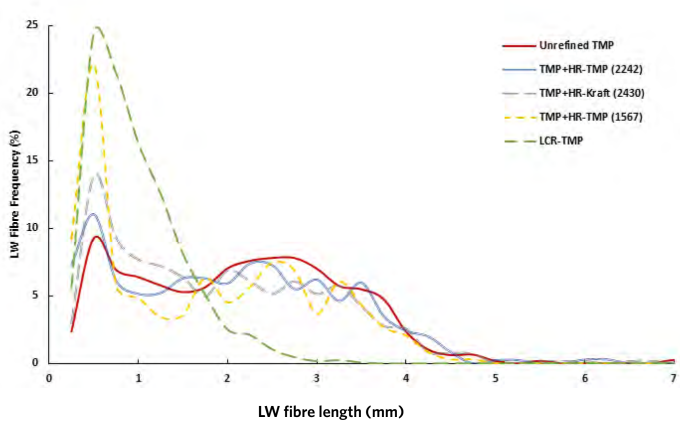


Figure 1: Fibre length distribution of LCR TMP and composites made with the addition of HR fibres to primary TMP.

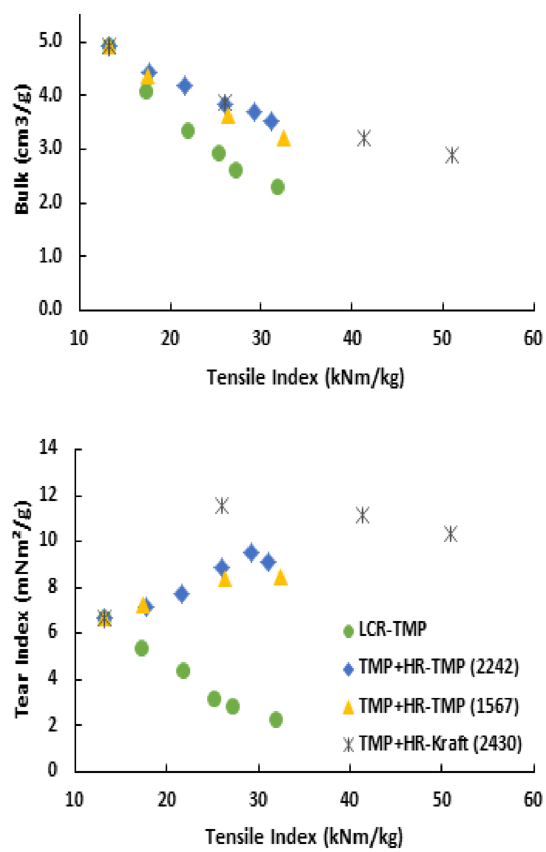


Figure 2: Higher bulk at a given tensile for all composites made with HR fibres (top); Tear index decreased with increased tensile index for LCR TMP and increased with the addition of HR fibres to unrefined primary TMP (bottom).

LCR HIGH ENERGY TMP MICRO-FIBRE FOR HIGH BULK, HIGH TEAR AND HIGH TENSILE MECHANICAL PULP

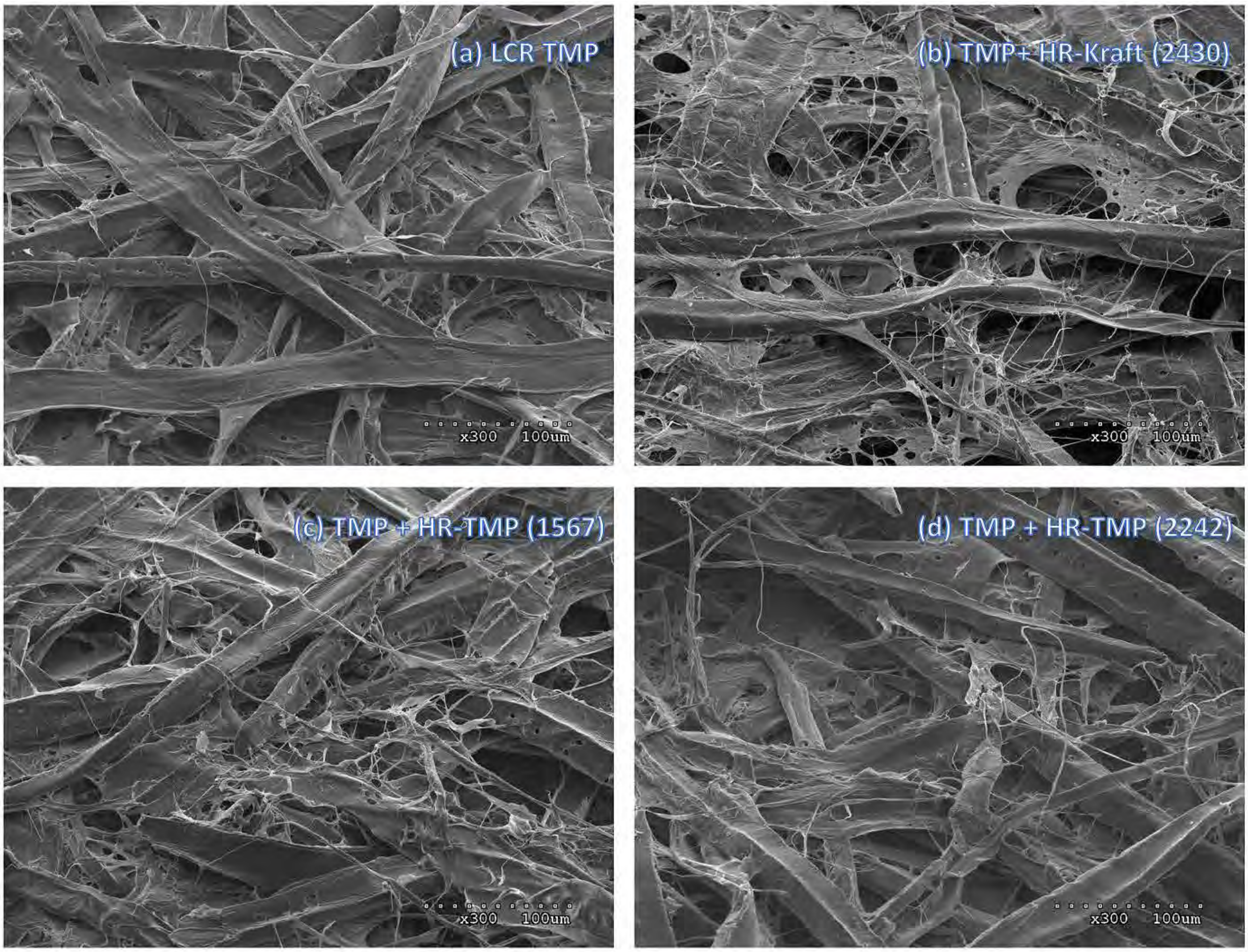


Figure 3: SEM images of surface of handsheets produced from LCR and composite samples, all at 315 kWh/t specific energy:
(a) LCR-TMP refined to 315 kWh/t: collapsed fibre creates low bulk handsheets.
(b) Composite handsheet made with the addition of HR-kraft to unrefined TMP: long hair-like fibrils traps long intact TMP fibres through web-like structures.
(c) Composite made by mixing 20% HR-TMP at 1567 kWh/t with unrefined TMP: fibrils are not well fragmented.
(d) Composite made with 14% HR-TMP at 2242 kWh/t: well developed fibrils draped around intact TMP fibres.
Images were captured at 45 degree angle to the plane of the handsheets with a magnification of 300.

MEETINGS AND PILOT PLANT TRIALS

Every year we host two Steering Committee meetings. Our last Steering Committee meeting was held at the UBC Vancouver campus on November 17, 2016. We had an excellent turnout, with many industry partners attending and all researchers presenting progress updates. We also organized breakout sessions to discuss research and trial priorities, with groups focused on sensors and controls, treatments and pre-treatments, and mill-pilot trial comparison and new products. That week, researchers also took the chance to have additional discussions with visiting representatives from Holmen Paper and Meadow Lake Pulp.

The 2016 Andritz trials took place at the Andritz R&D Center in Springfield, Ohio, from November 28 to December 2, 2016. The focus was on bleaching and LC refining conditions of softwood TMP to save energy. Bleaching and LC refining trials were conducted with pulp provided by Catalyst Paper – Powell River, from both double disc and single disc primary refiner lines. Prof. James A. Olson, Meaghan Miller, Emilia Jahangir and Yu Sun attended from UBC and trial results are currently under analysis.

Emilia Jahangir, Reanna Seifert and Meaghan Miller collaborated on a number of trials and projects with researchers and industry partners at UBC's Pulp and Paper Centre low-consistency refining pilot plant over the last several months.

As part of Reza Harirforoush's work on project 2.2, "LC refiner bar force sensor based control strategies", LC refining trials were conducted in March 2017 to further investigate the bar force sensors. Bar force sensors were tested with a new plate pattern and a range of pulp furnishes, including hardwood, different varieties of softwood and NBSK. Following these trials, additional recirculation trials were conducted using the bar force sensor to investigate the force-power-gap relationships with changes in fibre morphology.

A number of low consistency refining trials in continuous recirculation mode were carried out in March 2017 in collaboration with Quesnel River Pulp to investigate the effect of refiner disk speed and plate pattern on LC refining of high freeness reject pulp.

We look forward to continued meetings, visits, and trials with all ERMP members in 2017.

OTHER ERMP NEWS

Dr. Yu Sun, who worked with the ERMP program as a post-doctoral Fellow from 2014 to 2017, recently started work with Catalyst Paper – Crofton as a TMP Operations Specialist. She is already collaborating as a partner representative with the ERMP program, including mill trials at Crofton with Dr. Wild and Reza Harirforoush's LC refiner bar force sensor.

ERMP alumnus Ramin Khoie is a Process Systems Solutions Engineer at AutomationX Industrial Solutions, since completing his MSc at UBC in 2016. Ramin and the AutomationX team are collaborating with Dr. Olson and ERMP staff to develop a new controls system on the UBC-PPC LC refining pilot plant.

PhD candidate Hui Tian (Project 2.1) delivered a seminar on March 24, to the Department of Chemical and Biological Engineering entitled, "Economic Model Predictive Control for Integrated High and Low Consistency Refining". Shayan Housseinpour, a co-op student from UBC, joined the project in January for a term asresearch assistant.

UBC Applied Science held an Engineering Open House for prospective undergraduate students on November 26, 2016. Reanna Seifert and Meaghan Miller provided a tour of ERMP projects and facilities at the Pulp and Paper Centre, including the LC refining pilot plant and pulp and paper lab, and it was great to see a strong interest from students and parents in the research facilities.

PUBLICATIONS

Conference paper: Tian, Hui, Quigang Lu, R. Bhushan Gopaluni, and Victor M. Zavala, '' Multi-objective Economic MPC of Mechanical Pulping Processes''. Paper presented at the 55th IEEE Conference on Decision and Control, Las Vegas, USA, December 12–14, 2016.

Journal article: Harirforoush, Reza, Peter Wild, James A. Olson, "In-Process Detection of Fiber Cutting in Low Consistency Refining Based on Measurement of Forces on Refiner". *TAPPI Journal*, 16 no. 4 (2017): 189–99.

RESEARCH TOOLS AND INSTRUMENTATION FUNDING

DYNAMIC SHEET FORMER TO BENEFIT ERMP PROGRAM

We are pleased to announce that Dr. Olson and his colleagues were successful in their application for NSERC's Research Tools and Instrumentation funding to purchase a Dynamic Sheet Former, to be housed at the Pulp and Paper Centre. The application was submitted in October 2016, and the funding announcement was made in April 2017.

The Dynamic Sheet Former (DSF) will benefit several existing research programs at the PPC, especially the Energy Reduction in Mechanical Pulping program, and will greatly extend our sample preparation and testing abilities.

Once the funding is released we look forward to purchasing the equipment, getting it installed and operational, and collaborating on projects that benefit both our researchers and industry partners.

We share an excerpt from our application document:
The DSF enables the formation of fibre-based sheets in order to investigate paper properties, forming fabrics, additives and grade development. Sheets can be produced with multiple layers, specific fibre orientation and a large range of basis weight, from fine papers to boxboards. Multi-layer sheets can be made with different pulp grades with excellent adhesion between the layers. The DSF also enables the use of a large range of fibre types (short, long, non-wood, synthetic and recycled fibres) and provides better retention of fillers and chemicals than a conventional sheet former. The rectangular sheets made with DSF can also be coated and calendared and are similar in quality to paper made with a commercial paper machine. The automated operation of DSF ensures higher sample quality and repeatability, and provides greatly enhanced flexibility to our current testing capabilities.

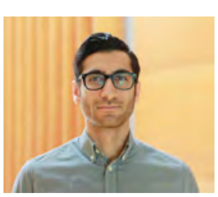
As the mechanical pulping industry transitions to low-energy biofibre production, we need to evaluate and optimize the performance of these fibres in new materials and next generation products, such as advanced composites, packaging and construction materials. Throughout the ERMP research program's 9-year history, the focus has been on developing low-energy fibres. A component of the ERMP consortium also focuses on new product development.

Currently, we are capable of testing the mechanical and optical properties of these low-energy fibres but we are not able to produce and characterize the novel products that incorporate them, for example, multi-layered board products for advanced packaging applications. The ability to do so is absolutely essential for both implementing the low energy processes as well as developing the emerging low-energy fibre materials and products.

The DSF is essential not only for TMP applications but also for emerging materials such as microfibrillated cellulose (MFC). Applications of MFC fibres as strength additives and for medical uses are gaining ground throughout the industry. However, this high value product is not routinely characterized and not explored to the full of its potential. The DSF will provide a platform to incorporate this high value material in various applications, including the formation of handsheets, which is typically difficult due to the low drainage. This will provide a new means for exploring the mechanical properties of MFC. The DSF will also allow us to explore the potential of MFC in coating and calendaring, something we are not currently able to do.

PAST ALUMNI SPEAK

Dr. Yu Sun
ERMP is a great research program with great team members. It allowed me to grow knowledge within and also outside of my major.



Ramin Khoie
Going through the ERMP program as part of the curriculum of my Master degree enabled me to expand my theoretical knowledge of pulping process and also practising it hands on in an industrial environment.

UPCOMING:

STEERING COMMITTEE MEETING
November 2017
UBC, Vancouver.

Invitations and details of the date, venue and time will be sent out early Fall.

CONTACTS

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PARTNERSHIP IS OUR STRENGTH

The supporting partners of this research program are:

AB Enzymes, Alberta Newsprint Company, Andritz, BC Hydro, BCIT, Canfor, Catalyst Paper, FPInnovations, Holmen, Meadow Lake Pulp, Millar Western, NORPAC, NSERC, The University of British Columbia Pulp and Paper Centre, The University of Victoria, The University of Toronto Pulp and Paper Centre, West Fraser, Westcan Engineering, and Winstone Pulp International.