Saving 1000 GWh/y through scientific discovery and the development of new technology

November 2009

Energy Reduction Research

OUR SECOND NEWSLETTER!

We are now almost three years into the five year $2.4M research program on "Electrical energy reduction in mechanical pulping". This summary is part of a semi-annual newsletter as a means of communicating with our partners the research highlights, successes, progress and upcoming events.

We have had an exciting 6 months. Much of the infrastructure is in place and many of the projects are yielding important results that we expect will lead to the development of new energy saving technologies and strategies. A highlight of this research is the results generated at the Andritz R&D laboratory where we demonstrated that chemical treatment and multi-stage LC refining can potentially eliminate the secondary stage of HC refining, saving approximately 1000 GWh/y.

We have also commissioned our pilot pump test facility in the last 6 months and are starting to add in our new pilot LC refiner.

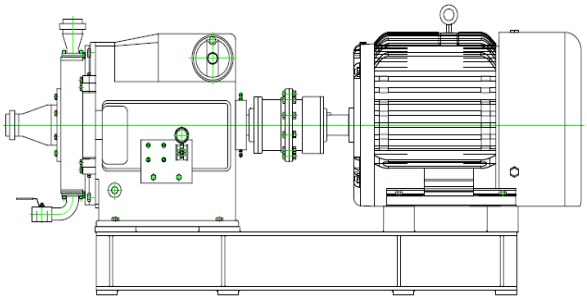
If you have missed our last newsletter you can get it my emailing james.olson@ubc.ca

UBC-PPC BUILDS PILOT LC- REFINING FACILITY

Aikawa / AFT-FineBar, and NSERC have partnered to build a state of the art LC refining facility in the UBC Pulp and Paper Centre. Aikawa will donate the new LC refiner, FineBar will donate plates, while NSERC has provided $142K to purchase the ancilliary equipment.

The new facility will expand on the existing pulp loop in the pilot plant and will consist out of:

- 2 x 4 m^3 tanks
- 2 x 15 HP agitators with VFDs
- 40 HP pump (450 GPM) with VFD
- 14" single disc refiner
- Instrumentation
    - Control valves
    - Power meter
    - Magnetic flow meters
    - Pressure and temperature
    - Gap position sensor
- 150 HP refiner motor with VFD
- Wide range of FineBar plates



UBC-PPC Pilot LC refiner.
(donated by Aikawa-AFT).

This state-of-the-art LC Refining facility will be used for fundamental research in this project, other sponsored research and contract research.

RESEARCH PROGRESS

Overview

This proposed, multi-disciplinary research program aims to reduce electrical energy

consumption in the mechanical pulping process by 1000 GWh/yr or 20% through scientific discovery and the development of new technology while maintaining or improving product quality and production. To accomplish this goal, we proposed a range of projects that span the risk-reward spectrum from incremental to transformative.

The program supports our shared vision that future mechanical pulp mills will transition to an increased reliance on energy efficient, low consistency (LC) refining and the reduction of high consistency mainline refining.

The program is composed of several projects that will combine theoretical, laboratory, pilot and mill scale experiments in the following strategic areas: Low consistency (LC) refining, latency removal, fibre fractionation, refiner control, novel mechanical pulping and mechanical strength and linting tendency of LC refined mechanical pulp.

1.1 Ultra-low intensity LC refining

Antti Luukkonen (PhD student)

This project aims to determine the energy savings potential of ultra-low intensity LC refining.

Three pilot LC refining trials have been completed at Andritz R&D laboratory in Springfield OH as well as a series of mill trials. These trials have demonstrated that specific energy and refiner gap are the two key variables in predicting pulp quality changes during refining. The trials have demonstrated that a minimum critical gap exists that if exceeded results in a significant loss in tensile strength. In addition, we have developed a means to predict gap depending on refiner design and operation.

From this research we will be able to ensure that LC refiners are operated at or near the maximum energy transfer available for a given installation and minimize the energy consumed in the less efficient HC refining process.

The 2008 study examined the effect of feed pulp freeness, refiner operation and plate design on pulp quality. Specifically, the effect of varying angular velocity, flow rate, plate design and power was determined for a range of feed pulp freeness of 120, 350, 550 ml CSF in a series of pilot refining experiments. Freeness drop was mostly affected by RPM with initial freeness, and tensile index increase was higher for high RPM and the higher edge load plate design. A linear drop was seen with the tear index drop with specific energy. A simple, empirical model of pulp quality changes is developed for a broad range of refining conditions.

The 2009 trials demonstrated the ability of a novel chemical treatments and multi-stage LC refining to eliminate the secondary HC refining stag, saving 1000 GWh/y, and producing equivalent pulp quality.

1.2 Chemical and biological treatments

David Kuan (Coop), 9 students (BCIT), Harry Chang (Researcher), Norm Weber (Arkema)

The objectives are to develop chemical and/or biological treatments that enhance the ability of LCR to be used as a process for reducing electrical energy consumption in refining through:

1. Surveying chemical and biological treatments used in HC refining
2. Selecting promising treatments and evaluating on a laboratory scale
3. Conducting pilot and mill trials.

Progress to date: A coop student, *David Kuan* replaced *Colin Bridges*, to work with research scientist *Harry Chang* on the project. The survey on chemical and biological treatments has been circulated to supporting companies

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and the research team. A system has been developed to assess low consistency refining on a laboratory scale. This system has been used to screen potential chemical and enzymatic treatments. Alkaline peroxide has proved to be most promising treatment with potential electrical energy savings of 20 to 50% to a given tensile strength. These laboratory results have been confirmed in trials at the Andritz pilot plant.

Both alkali and hydrogen peroxide are essential to achieve the energy savings. The savings are related to increases in the acid group content of the pulp, increased fibre flexibility and reduced fibre cutting.

Laboratory scale treatments with ozone and with oxygen reinforced alkaline peroxide, also show potential for electrical energy savings when combined with LCR. Enzyme treatments and treatments with oxalic acid provided no benefits.

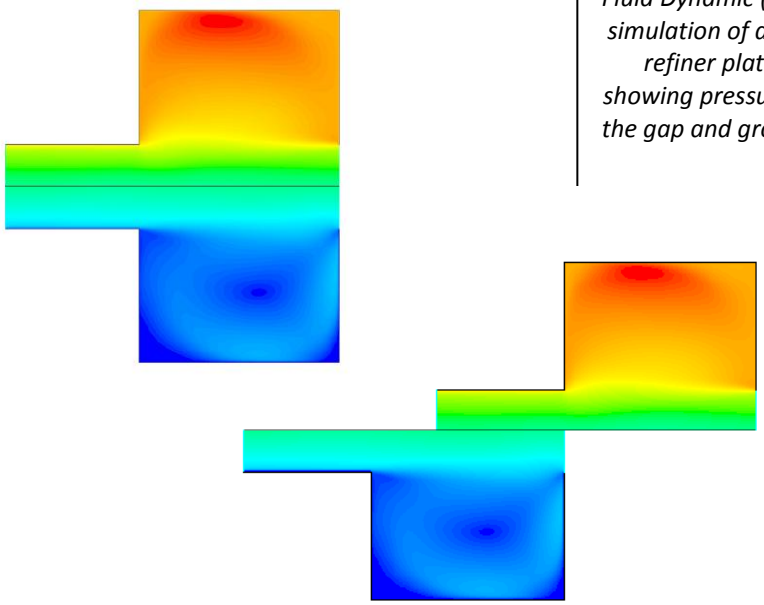
The goal of gathering information on chemical treatments in BC mills has been dropped to allow faster progress with laboratory, pilot and mill scale investigations.

1.3 Minimizing no-load power

J. Kerekes (Summer student), Nina Rajabinasab (PhD student)

The objective is to determine the effect of pulp suspension rheology and plate design and refiner operation on the no-load energy losses in LC refining. Further, a theoretical model of no-load will be developed and compared to pilot and mill trials. The project is being conducted by a doctoral student *Nina Rajabanisab*.

Since the last newsletter, Ms *Rajabinasab* has initiated three separate yet complimentary studies. In the first study is essentially an experimental protocol in which she measured the power consumption as a function of plate geometry, flow rate, rotational speed, and gap position. She is currently completing a dimensional analysis of her results in order to provide a statistical model for prediction of no-load power.



Computational Fluid Dynamic (CFD) simulation of an LC refiner plate showing pressure in the gap and groove.

In the second project, Ms *Rajabinasab*, is conducting a comprehensive computational study of the flow pattern found in a refiner. She has structured her work in two stages: 2D and 3D simulations. She has currently completed the 2D simulations and is proceeding to construct a robust 3D code. In addition she has had a number of idealized refiner plates manufactured, in-house, to validate her code.

In the third section of her work, Ms *Rajabinasab* has initiated another experimental program to characterize the hydraulic pressure in a LC refiner under no-load conditions. With the assistance of Mr. *J. Kerekes*, a summer student, high-speed data was acquired of the pressure signal in the groove of the stator plate. The data is currently being analyzed.

We anticipate that the results of these studies will be reported as three separate publications next year.

1.4 Theoretical estimates of energy and intensity in LC refining of mechanical pulp

Dick Kerekes and Ali Elehimehr (PhD Student)

Objectives and approach: To derive a rigorous theoretical understanding how energy is used in mechanical pulping, with the ultimate aim of identifying precisely where and how energy might be reduced.

1. Make new estimates of the theoretical energy needed in refining, identifying the energies lost in elastic, plastic components of strain and hysteresis losses in wood viscoelastic behaviour in the creation of new surface area.
2. Estimate the energy per impact per fibre in HC and LC refining using the same basis and the same assumptions.
3. Convert the above energy-based characterization to a "force-based" approach by estimating the forces on bars.
4. Convert the forces on bars to forces on fibres.
5. Estimate the strains in fibress from forces on fibres and the physical properties of wood fibres.
6. Compare estimated strains to the "theoretical strains" estimated in part 1 and thereby verify the sources of energy consumption.

Progress to date: Recent work has focused on developing a force-based refining intensity for LC and HC refiners. Based on the Specific Edge Load (SEL), forces on bars per bar crossing per bar length have been estimated. Using estimates of fractional bar coverage of bars by fibre, forces on fibre mass were also estimated and found to compare favourably with recent measurents by researchers from the University of Victoria.

With further assumptions, forces on indivuidual fibre were estimated. Although approximate in magnitude, the analysis showed clear trends, one being a strong dendence of fibre force on both SEL and gap size. Given that SEL itself depends on gap size, this shows that forces on fibres increase dramatically with descreasing gap size. This finding offers an explanation for the findings of Murton et al for HC refiners, namely, that gap size corelates better with pulp properties than either energy-based refining intensity or residence time.

1.4 Optimal pumping efficiency in LC and MC treatments

Imad AbuYousef (MASc student)

Objectives: To design and build a pump test facility that accommodates the LC refiner loop, and to experimentally and theoretically determine the impact of pump design and operation on efficiency.

The pilot test facility has been commisioned. The design has been modified several times to accomodate a range of experiments. Pump efficiency will be experimentally determined for a range of speeds, impeller trims, pulp types, consistency and air bubble content. The impact of bubble content on the suction side of the pump and its impact on NPSH will also be determined. Finally, a rheological model of pulp suspension pumping efficiency will be developed that will enable improved design and operation of pulp pumping and pipe systems.

2 Latency removal

Jiyang Gao (PhD student)

The optimization of energy use in the recovery of the latent properties from mechanical pulp is being studied in the context of the complete fibre line. To accomplish this we will:

1. Measure the kinetics of latency removal as a function of pulp type, treatment temperature, suspension consistency, and agitation intensity.
2. Develop a dynamic model of freeness in the chest and optimize the ability of a chest to develop the latent potential of the pulp.
3. Examine alternative strategies for efficient latency removal in context with a number of modified mechanical pulp fibre lines..

We have now completed his literature review, comprehensive exam and department seminar. The design for the laboratory latency tester has been delayed, but is now nearing completion and will be sent for fabrication later in the year. Experimental characterization of latency removal will begin once the equipment is commissioned. The testing protocol has been developed based on studies made with available literature data and some preliminary tests made with mechanical pulp obtained from one partner mill. Bench-top tests have shown that fibre straightening can take place in the absence of mechanical treatment, but that mechanical treatment is necessary to significantly reduce freeness. Characterization of latency removal dynamics and efficiency from existing latency removal chests in one partner mill are now underway and will be used to guide later experiments and validate our models.

3 Novel fibre fractionation

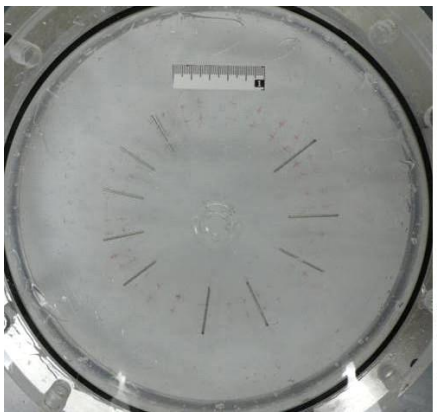
Ario Madani (PhD student)

Objectives and approach: The main objective of this work is to develop a prototype device to effectively fractionate fibres by wall thickness.

1. Explore use of non-Newtonian fluids for separation
2. Develop a continuous laboratory separation proof-of-concept
3. Develop a pilot scale prototype

Progress to date: The doctoral student *Ario Madani* has made exception progress during the past period. He has completed four separate experimental studies to show (a) the concept proposed is correct and is a viable technique for particle sorting; (b) has demonstrated that batch wise, this methodology is able to separate chemical pulp suspensions based upon either length or coarseness;(c) has demonstrated that the technique is viable to separate commercially microfibrillated cellulose fibres into different length classes; and (d) has shown the efficiency of the methodology in separating is greater than commercially available technologies.

During the reporting period the work has been presented at one scientific conference and been accepted to a scientific journal.



Separation of fibres of different length in our novel non-Newtonian fractionator

4 Refiner control

Eranda Harinath (PhD student)

The objective of this project is to ensure that existing and to-be-developed mechanical pulping processes (TMP) are operated at minimal energy consumption in the presence of dynamically changing availability and cost of electrical energy while meeting pulp

production and quality objectives. The progress of this project:

1. Development of closed-loop identification techniques which will be used to update the model of TMP process. This updated model will be used in the linear model predictive control (MPC) strategy for set-point tracking in the current TMP process.
2. Development of a nonlinear MPC (NMPC) to dynamically optimize a primary TMP refiner process in the presence of constraints. The constrained optimization problem is considered to minimize motor load and to maximize production rate subject to pulp quality measurements constraint.
3. Development of a NMPC for optimum set-point tracking of a primary TMP refiner in the presence of constraints.

The PhD student (*Eranda Harinath*) is focusing on developing optimization techniques required to fulfill the objective of this project. In the last year he has visited the Catalyst Elk Falls mill several times, in order to set-up the initial stage of system identification. Unfortunately, the mill has now been closed for several months with no indication of when it will start up again. Presently *Eranada* is simulating a TMP production line using Matlab/Simulink and working on this simulated process to develop algorithms. We hope to extend one by one the above developed algorithms to include a secondary TMP refiner and a third stage LC refiner. Ultimately, we will thus integrate the whole refiner line. In the mean time, in summer 2010 Eranda expects to visit the centre for advanced process decision-making (CAPD) at Carnegie Mellon University, the world-leading research group on real-time optimization. There, he will further develop control and optimization techniques for the TMP refiner process.

Recently, a postdoctoral fellow (*Mohammed Ammar*) has joined this project to develop dynamic data reconciliation (DDR) techniques, as well as closed-loop identification techniques. An extensive literature review on DDR and NMPC has been done. First, we have selected the Quesnel River Pulp (QRP) mill as a candidate mill for this project. We are currently working on developing a CADSIM TMP model provided by QRP to fit our research objectives. Convex optimization analysis is being investigated to solve the DDR problems. Mohammed and Eranda are currently working with Aurel Systems Inc. to improve the current DDR techniques in CADSIM.

Taegeun Kang and Joe Kerekes conducting a novel refining trial.

5 Novel mechanical pulping

Taegeun Kang (Post doctoral fellow)

Objectives: To develop a new, transformative technology for the energy efficient reducing of pulp wood into individual fibres suitable for high quality, lint-free mechanical printing papers.

It was possible to produce wood shavings with longer fibre length than wood chips. LC refined wood shavings were found to be a low energy raw material. The refining energy was reduced by about 33% using wood shavings compared to wood chips at a given freeness, and oxalic acid pretreatment of wood shavings further reduced the refining energy by about 57%. Tensile strength and brightness of LC refined wood shavings was found to be higher than HC refined wood chips. Oxalic acid pretreatment further improved the tensile strength of LC refined wood shavings, but not the brightness. This study demonstrates the potential to develop a novel mechanical pulping process that produces high tensile, high brightness pulp with half the electrical energy consumption.

Jens Heymer, a PhD Graduate student from UBC, was hired in order to continue the excellent work done by *Taegeun Kang*, who left the team for a career in the New Zealand Pulp and Paper industry.

6 Mechanical strength and linting tendency of low consistency refined pulps

Pawel Trocki (MASc student)

The aim of the project is to examine the effect of LC refining on fibre characteristics, paper structure, and the resultant paper properties. In particular, we seek to understand the effects of LC refined pulp substitution on the important paper properties through a detailed structural analysis of a variety of sheets:

1. Conventional TMP
2. TMP refined with greater energy input in the LC stage
3. Chemically pre-treated TMP refined with greater energy input in the LC stage

A MASc student at the University of Toronto, Pawel Trocki, is currently working on this project. A series of preliminary LC refining trials was carried out using 120 CSF market MP as feed. The trials were designed to assess the LC refining effects on pulp properties over a range of refining intensity values (between 0.2 to 0.6 J/m) – measured at set specific energy amounts (up to 320kWh/t). One set of the trials took place at UBC and utilized their experimental disc refiner, while the second set of trials was performed at FPInnovations/Paprican-BC with an experimental conical refiner. Basic mechanical property analysis of these samples showed that these pilot refiner trials yielded results that were not representative of commercial sheets, and therefore further analysis of these samples has been suspended. The work will now focus on the analysis of representative pulp samples produced in the recent LC trials conducted at Andritz. In particular, the plan is to characterize the structural differences between the LC refined pulp with and without chemical pre-treatment as well as conventional TMP pulp refined to the same freeness. We are in the process of acquiring these pulp samples from UBC and BCIT.

PUBLICATIONS

Significant publications and reports from the sponsored research:

1. Kuhn, R. and Green, S.I., "On Site Measurement of Kraft Pulp Pump System Efficiency", Pulp and Paper Canada, vol. 109, no. 4, pp. 23-30, April 2008.
2. A.Madani, J. Salmela, S. Storey, J. Olson, I. Frigaard,and M. Martinez “Fractionation of rod-like particle suspensions in a viscoplastic fluid” Chemical Engineering Science (in press).
3. A. Madani, S. Storey, J.A. Olson, I.A. Frigaard, D.M. Martinez, University of British Columbia, Canada; J. Salmela, VTT,

Finland, "Novel fractionation methods: separation in a viscoplastic fluid", 14th Fundamental Research Symposium, St. Anne's College, Oxford, 13-18 September 2009.
4. Xue-Feng Chang, David Kuan and Rodger P. Beatson "Saving Electrical Energy in Refining. Part I: Treatment with Alkaline Peroxide" PACWEST Conference, Kamloops, BC, June 10-13, 2009.
5. Kaleb Fisher, Jessica Hilton-McPherson, Michelle von Schilling, Derrick Villanueva, Norm Weber, Xue-Feng Chang and Rodger P. Beatson "Saving Electrical Energy in Refining Part II: Treatment with Ozone" PACWEST Conference, Kamloops, BC, June 10-13, 2009.
6. Jun Yan, Eranda Harinath and G. A. Dumont, "Tuning and Identification for Model Predictive Control: An Iterative Approach," In Proceedings of IFAC Symposium on System Identification, St. Malo, France, July 6-8, 2009.
7. Jun Yan, Eranda Harinath and G. A. Dumont, "Closed-loop Identification for Model Predictive Control: Direct Method," 48thIEEE Conference on Decision and Control, Shanghai, China, Dec 16-18, 2009.
8. Eranda Harinath, Jun Yan and G. A. Dumont, "Closed loop Identification with Constrained MPC: Joint input-output method," submitted American Control conference (ACC), 2010.
9. Eranda Harinath, Jun Yan and G. A. Dumont, "Multivariable control of TMP refiner line: A simulation study", in preparation to submit to Annual Meeting of PAPTAC, 2010.
10. Taegeun Kang, George Soong, Harry Chang, Rodger Beatson, James A. Olson and D. Mark Martinez, "Low Consistency Refining of Oxalic Acid Pretreated Wood Shavings", in preparation to submit to Annual Meeting of PAPTAC, 2010

EVENTS

PAST EVENTS

International Mechanical Pulping Conference, Sundsvall, Sweden, June 1-4, 2009

We presented two papers on our research. One examined the potential energy savings available by using shavings as a raw material and directly feeding them into LC refiners and the second paper presents what we learned from the pilot LC refining trials.

PACWEST Conference, Kamloops, BC
June 10-13, 2009

UPCOMING EVENTS

PAPTAC Annual Meeting, Montreal, QC
February 2-3, 2010

Three students will present posters on their work as well as their research progress during the PAPIER Student Seminars and Poster Session.

SPONSORS

The supporting organizations of this research are: AFT-Aikawa Group, Andritz, Arkema, BC Hydro, Canfor, Catalyst Paper, CEATI International, FPInnovations, Honeywell, Howe Sound Pulp and Paper Limited Partnership, NSERC, Ontario Power Authority, Quesnel River Pulp, the University of Toronto Pulp & Paper Centre and Westcan.

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