A Pilot Scale Comparison of the Effects of Chemical Pre-treatments of Wood Chips on the Properties of Low Consistency Refined TMP

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Abstract

After decades of research and development, the technology of thermomechanical pulping (TMP) has dramatically improved resulting in higher pulp quality, especially strength. However, the TMP industry is still faced with the challenge of continually increasing energy costs. One approach to reducing the energy costs is to replace the second-stage high consistency (HC) refiner with several low consistency (LC) refiners. This is based on the observation that low consistency refining is more energy efficient than high consistency refining. The limitation of LC refining is loss of paper strength due to the high frequency of fibre cutting especially at high refining intensity. Chemical treatment combined with low consistency refining provides opportunity for even further energy savings. The chemical treatment could improve pulp properties allowing for further energy reduction in the HC refining stage or reduced intensity during LC refining resulting in less fibre cutting. Indeed, it is also possible that the chemical treatment itself will improve the resistance of the fibre to the cutting during LC refining.

In this pilot mill (ANDRITZ Springfield R&D Center) research work, the effects of impregnating softwood chips with different chemicals on the properties of the pulp obtained through single-stage HC refining followed by multiples stages of LC refining have been evaluated. SPF (Spruce, Pine & Fir) chips were treated with sulphite, alkali (NaOH) and alkaline peroxide ($NaOH+H_2O_2$) and then HC with energy input in the range of 647 to 735 kWh/ODT. These HC refined pulp were shipped to the UBC Pulp and Paper Centre in Vancouver where they were LC refined in multiple stages over a wide energy range to produce a wide range of freeness levels. The effects of the treatments on total energy consumption, freeness, pulp properties and fibre morphology were evaluated.

The alkaline peroxide pre-treatment significantly reduced the energy required, during the entire refining process (HCR + LCR), to produce a pulp at a given tensile index compared with the other chemical treatments and the control pulp. For the alkali treatment, less total energy was required to attain a given tensile compared to control pulp, but more energy was consumed in order to reach a desired freeness. An interesting observation is that the alkali treatment produced pulps with higher fibre length, at the same energy input, compared to all the other three trials. The sulfite treatment provided modest energy saving, to a given tensile.

The improvements in tensile index obtained through the chemical treatments was accompanied by a loss in light scattering coefficient especially for the alkali and alkaline peroxide trials. Among the three chemicals, only sulphite offered some improvement in bulk at a given tensile, whereas alkali gave the lowest bulk value at a given tensile. Sulphite treatment resulted in a small increase in tear index at a given tensile compared with control pulp, whereas both alkali and alkaline peroxide gave the highest tear at a given tensile index.

Introduction

Compared with other mechanical pulping processes, TMP is recognised as a high energy consumption process although it could produce pulp with longer fibre length and lower shive content [1]. To reduce the energy consumption in TMP while maintaining or improving the pulp properties is always the main goal when developing new mechanical pulping technologies. In recent years, major progress in mechanical pulping processes has occurred through developments such as novel technology and equipment for chip pre-treatment, such as Andritz Impressafiner [2] and fundamental research on and application of low consistency refining technology [3]–[5].

As refiner mechanical pulping has evolved, developments in the process have been accompanied by the application of chemical treatments with the main aim of improving pulp properties [6]. Traditionally, chemicals such as sulfite, alkali or alkaline peroxide are either used to treat wood chips prior to first stage high consistency (HC) refining, or applied during an inter-stage treatment between the primary and secondary HC refining. Sulfite pretreatment on wood chips followed by single or two-stage HC refining has been studied by several researchers. In the recent work of Nelsson et al. [7], in the production of TMP with a tensile index of 47 Nm/g, about 15% of the total specific refining energy was saved when Norway Spruce wood chips were pretreated with 1.2% Na_2SO_3. In the same study, they also found that low dosage sulfite (0-1.2% Na_2SO_3) pre-treatment did not significantly affect the distribution of the Bauer-McNett fractions or the mean fibre length for pulps refined with equal specific energy consumption. In a study by Xu [8], 3.4% sulfite was applied on spruce wood chips prior to high-consistency refining and the results showed that different chemical liquor temperatures (25^{o}C vs. 160^{o}C) have little influence on the results. Alkaline peroxide, widely used as bleaching agent in the mechanical pulping industry [9], also has great potential for reducing the refining energy required to produce a pulp of certain tensile strength. Moldenius [10] found that depending on the ratio of alkali and peroxide charge, alkaline peroxide treatment of mechanical pulp could enhance both brightness and tensile strength. In a study by Chang et al. [9], an alkaline peroxide treatment on secondary HC refined pulp at a pH around 13 resulted in pulp with improved tensile strength that also had higher resistance to fibre cutting during subsequent LC refining[11]. The improved strength properties caused by alkaline peroxide treatment was found to be closely related to the generation of acid groups on the fiber surfaces and in the fines [12]. Based on the author's knowledge, no published study on alkaline peroxide pretreatment of wood chips following by HC and LC refining is available.

In this study, we evaluate the effects of different chemical pre-treatments of wood chips on the properties of TMP produced by a single stage of pressurized HC refining followed by multiple stages of low consistency refining. Three different chemicals (sulfite, alkali and alkaline peroxide) were applied on SPF wood chips using RTPressafiner. These mechanically and chemically pre-treated chips were HC refined to a freeness range of 500 ml to 650 ml, using an Andritz 36-1 CP pressurized single disc refiner. The subsequent low consistency refining was carried out for each trial using a recirculation loop (details given in 'Experimental') and an Aikawa 14" refiner. For LC refining, each trial involved 6 samples taken at no load power, and after each pass through the refiner.

Experimental

Material and preparation

This investigation used SPF chips from Quesnel River Pulp mill in Quesnel, BC, Canada. These chips were shipped from BC to the Andritz R&D pilot plant in Springfield Ohio.

RTPressafining/Impregnation

The SPF chips were compressed and destructed using the Andritz RT Pressafiner. The chips were steamed for 15 seconds at a pressure of 20 psi before being fed into the press, the screw RPM was 36 and the outlet restriction was set at 0.5". Chemical liquor was applied at the discharge of the press. Three different chemical treatments were studied with one more trial using only water during impregnation as a control. The detailed chemical charges for each treatment are shown in Table 1. For each trial, the pH of outlet liquor after impregnation was also measured.

Table 1: Chemical impregnation during RT Pressafining

Trial code	Chemical Treatment	pH
1	Control (water only)	
2	Sulphite 2.05%, 0.07% DTPA on O.D wood	8.4
3	NaOH 5%	13.3
4	NaOH 3.9% + H_2O_2 1.8% + Stabilizers*	13.1

**2% sodium silicate, 0.4% DTPA and 0.1% MgSO4 on O.D. wood chips*

High Consistency Refining

The impregnated chips were high consistency refined using an Andritz 36-1CP pressurized single disc refiner operating at a refiner disc speed of 2300 RPM and pressure of 3.1 bar. The pre-steam pressure was 20 psi and the retention time of steaming was around 20 to 30 seconds. The chemical treated and non-treated chips were HC refined under similar specific refining energy in order to produce pulps at similar freeness level. After HC refining, the high freeness pulps from alkaline and alkaline peroxide treated chips were neutralized and washed before shipping back to the Pulp and Paper Research Centre at UBC in Vancouver, BC. The specific refining energy and properties for the HCR pulps are shown in Table 2.

Table 2 SRE and pulp properties during HC refining

	SRE (kWh/o.d wood)	Freeness (mL CSF)	Tensile Index (N.m/g)	Tear Index ($mN.m^2/g$)	Brightness (% ISO)
Control	704	573	11.37	5.18	45.8
Sulphite (Na_2SO_3)	680	580	13.58	5.90	48.2
Alkali (NaOH)	697	648	14.82	8.24	23.1
Alkaline peroxide ($NaOH+H_2O_2$)	647	642	16.28	8.58	37.3

Low Consistency Refining

These HCR pulps were then low consistency refined using an Aikawa 14" single-disc LC refiner. A small continuous recirculation system was used to allow the multiple passes of pulp through the LC refiner to obtain pulps refined over a range of specific refining energies having different freeness levels. For each trial, re-pulping was done with 50-60^oC tap water for 15 minutes to ensure proper mixing. The schematic of LC refining system is illustrated in Figure 1. All the LC refining trials were carried out with targets of 1200 rpm refiner speed, flow rate of 250 L/min, 3.5% pulp consistency, 0.5 J/m specific edge load and 2.74 km/rev plate bar edge length.

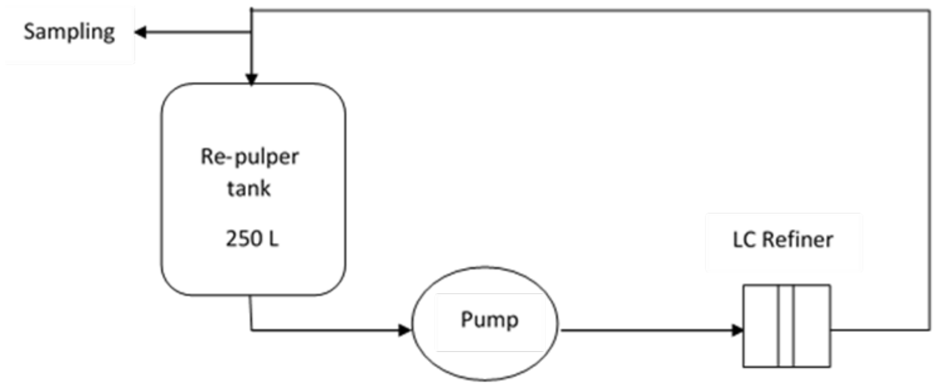


Figure 1 The schematic of LC refining system

Measurements

After HC and LC refining, according to PAPTAC method C.8P, the pulps were disintegrated in hot water to remove latency. Then, freeness of pulps was measured under the PAPTAC standard method C.1. A Fibre Quality Analyzer (OpTest Equipment, Canada) was used to test the mean fibre length and fines content under ISO method, which means the fraction of fines were excluded for calculating the fibre length.
Pulp properties were evaluated on 60 g/m^2 handsheets prepared with a British sheet-mould former according to PAPTAC method C.4. Handsheets physical properties were measured according to PAPTAC methods D.34, D.9 and D.8. The brightness and opacity were determined using PAPTAC methods E.1 and E.2. The light scattering coefficient and the light absorption coefficient were measured using TAPPI method T1214.

Results and Discussion

In this study, the initial wood destructing was realised using a high compression screw feed conveyor to commute the wood chips into small wood fragments that make the wood amenable to fibre separation. Then, these wood fragments were chemically treated during impregnation stage and high consistency refined at high intensity in a single stage refiner. The resulting pulp is then LC refined. The focus of this study is to compare the effects of three different chemical pre-treatments on the properties of LC refined pulp.

As shown in Figure 2, chemical pre-treatments on wood chips reduce total refining energy consumption (including HC and LC stages) to produce pulp of a given tensile index. Among the three chemical treatments investigated, alkaline peroxide turns out to be most effective in reducing the specific energy required to obtain a given tensile index. With an alkaline peroxide (NaOH 3.8% + H_2O_2 1.8%) application to compressed wood chips after the RTImpressafiner, about 950 kWh/t energy was needed to produce a pulp at a tensile index of 40 N.m/g. To produce pulp at the same tensile index level, it is estimated that 1180 kWh/t would be needed for the control pulp where no chemical is involved (Figure 2). In this study, different chemicals have been applied on wood chips during impregnation after RT-pressafining, reducing specific energy requirements for a certain tensile during HC refining stage compared with control trial, especially for the alkaline peroxide pre-treatment trial. More details on the effects of chemical pre-treatments of wood chips on the properties of the high consistency refined pulps from this trial are discussed in a separate paper [13].

Compared with the control trial, sulfite pre-treatment also shows advantage in energy saving but the amount is limited. However, the energy savings become larger on LC refining to higher tensile index. Nelsson et al. [7] also investigated the effect of sulfite pretreatment on wood chips but followed by two stages of high consistency refining. In that study, with the same total refining energy of 1950 kWh/t, the tensile index of pulp from sulfite pre-treated wood chips is 47.2 N.m/g while the tensile index of control pulp is 42.9 N.m/g. Differing from Nelsson et al.'s work, this time sulfite pre-treatment was combined with first stage high consistency refining and followed by multiple stages of low consistency refining. As shown in Figure 2, with a total energy consumption of 1000 kWh/t, the pulp from sulfite pretreatment trial has a tensile index of 34 N.m/g, and the control pulp has a tensile index of 30 N.m/g. The improvement on tensile index at a certain energy consumption level from these two works are similar.

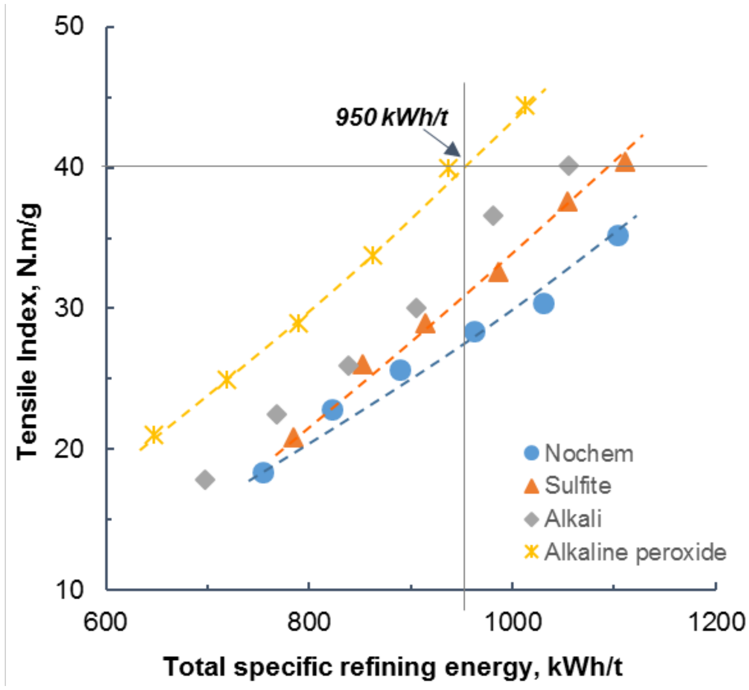


Figure 2 - Correlation between tensile index and Total SRE

The development of the tensile index during low consistency refining for each trial can be observed in Figure 3. Compared with the control trial, the tensile index of chemically pre-treated HC refined pulps develops faster during low consistency refining. This indicates that chemical pre-treatments on wood chips could promote fibrillation of fibres during LC refining compared to the control pulp. An interesting finding is that no obvious difference could be observed in the development of tensile during LCR among the different chemical pre-treatments. This is in sharp contrast to the results of HC refining, where alkaline peroxide treatment showed significantly positive effect on improving tensile index at a specific energy compared to two other chemicals.

The tensile index for all the trials increased linearly with the increase of energy consumption during LCR. In a previous study by Chang et al. [12], alkaline peroxide treatment was applied to primary HC refined hemlock pulp before LC refining. In that study, the tensile index increased rapidly from 30 N.m/g to 50 N.m/g with a specific energy consumption of only 300 kWh/t, and then the rate of increase slowed down, a plateau was reached at around a tensile index of 55 N.m/g. The different patterns of the development of tensile index during LCR from these two studies show the importance of considering the location of the chemical treatment for obtaining the desired properties and refining response. For alkaline peroxide treatment, the improvement of tensile strength is found to be dependent on the generation of carboxylic acid groups. Compared to wood chips, the HC refined pulp have much more surface contact area for chemical reaction, this may lead the different results on the increasing of tensile strength under same chemical treatment.

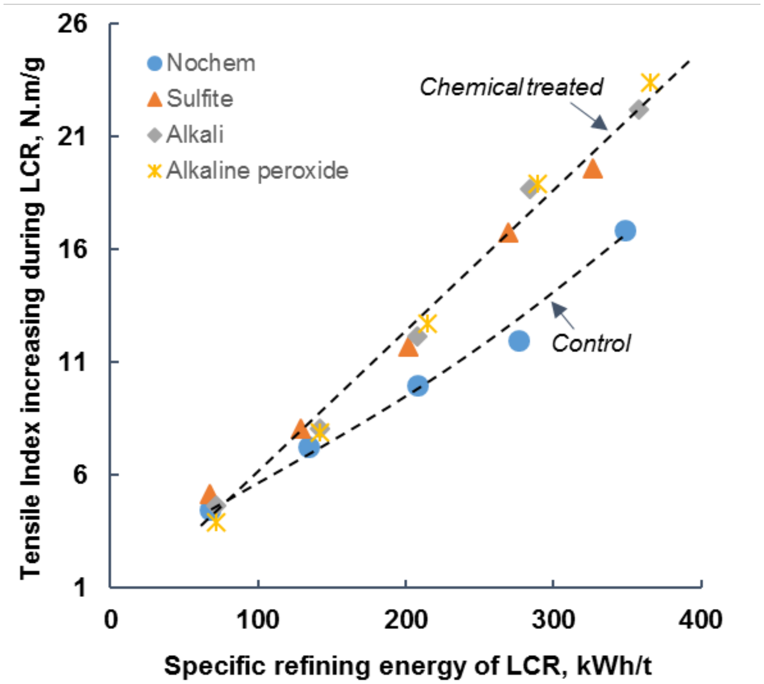
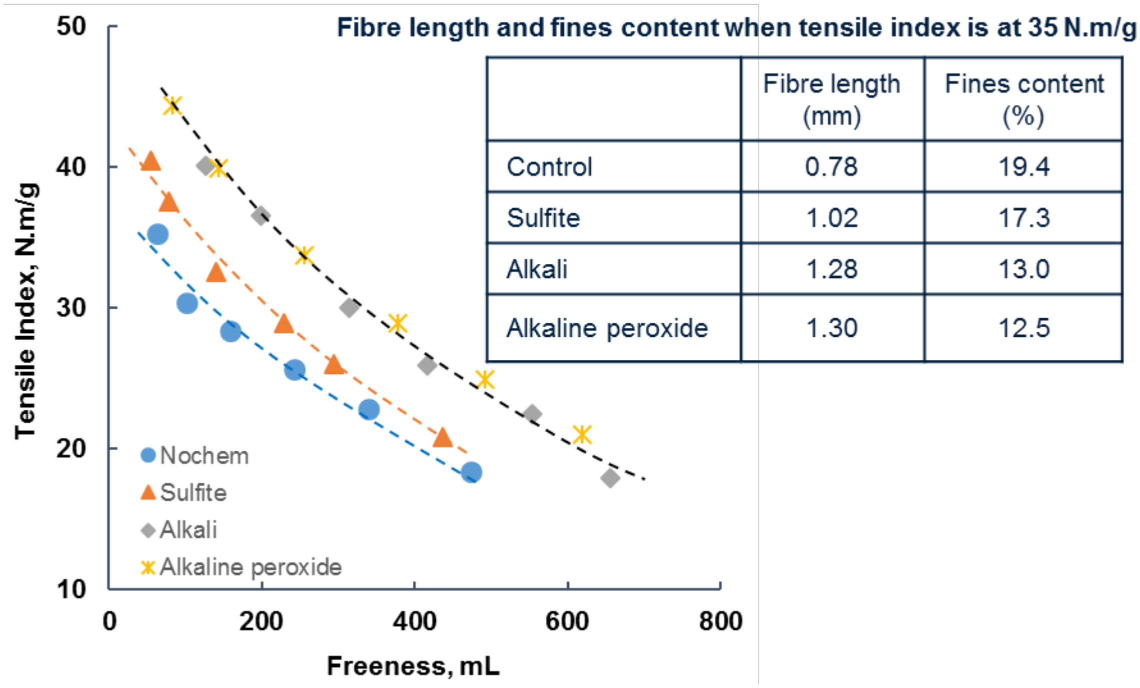


Figure 3 - Relationship between the increase of tensile index and SRE during LCR

The relationship between tensile strength and freeness is shown in Figure 4. Sulfite treatment causes a small increase in the tensile at a given freeness. The tensile/freeness relationships for the alkali and alkaline peroxide treatments are similar and demonstrate the highest tensile at given freeness. The higher tensile index at given freeness with alkali and alkaline peroxide pre-treatments is probably related to the observation that these treatments produced pulps with longer fibre length and lower fines content compared to the control and sulfite treatment. The data on fibre length and fines content could also be found in Figure 4. It is important to note that incorporation of chemical treatments into mechanical pulping processes changes the correlation between tensile development and freeness.



	Fibre length (mm)	Fines content (%)
Control	0.78	19.4
Sulfite	1.02	17.3
Alkali	1.28	13.0
Alkaline peroxide	1.30	12.5

Figure 4 - Correlation between tensile index and freeness during LCR

The high intensity of low consistency refining was always considered to cause fibre cutting and lower tear index. The tear index of a typical TMP is 7.5- 9.0 $mN.m^2/g$ at pulp freeness of 100-150 mL [1]. In this study, during low consistency refining, the tear index of control pulp decreased from 7.5 to 2.8 $mN.m^2/g$ with the tensile increase from 18 to 35 N.m/g. The main reason for the drop in tear is probably the fibre length decrease from 1.63 to 0.8 mm, as it is well known that tear is known to be much more dependent of fibre length than is tensile strength [14].

As shown in Figure 5, chemical pre-treatments have a positive effect on tear index. Sulfite pre-treatment offered a slight higher tear index at all levels of tensile index compared to control. The most interesting point is that with alkali and alkaline peroxide pre-treatments, the tear index after HC refining is about 11 $mN.m^2/g$ which is 6 units higher compared to the control trial. Although the drop of tear index with increasing tensile index on refining the pulps from the alkaline and alkaline peroxide treated chips is faster than for the control, even at the highest tensile index of 45 N.m/g, the tear index for these two treatments is still two times higher than both control and sulfite trial.

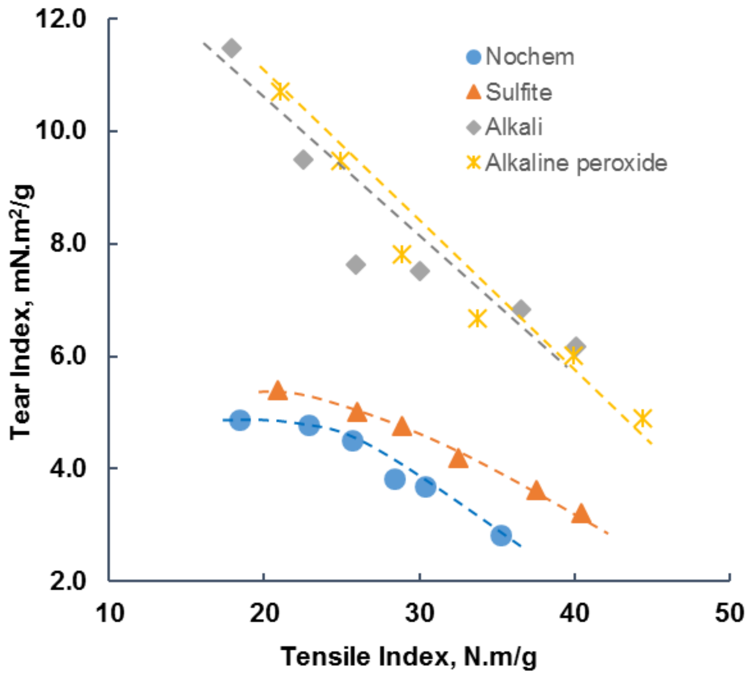


Figure 5 - Correlation between tear index and tensile index during LCR

High light scattering coefficient at a given tensile index is very important for printing paper. In this study, the three chemical pre-treatments on wood chips didn't show positive effects on improving the light scattering coefficient compared with the control trial. No obvious difference could be observed on light scattering coefficient between the pulp from sulfite trial and control trial, as shown in Figure 6. This result is in consistent with the study of Nelsson et al. [7]. Some other researchers [15], [16] reported an increase of light scattering coefficient at sulfonate contents below 0.2% compared to unsulfonated pulp at a given specific energy consumption. Alkaline peroxide pre-treatment on wood chips decreased the light scattering coefficient of HC and LC refined pulp when compared to the pulps from chips that had not been treated or sulfite treated. One possible reason for this is that the generation of fines was decreased when wood chips were pre-treated with alkaline peroxide and fines play an important role in contributing to light scattering coefficient [17]. These results are in sharp contrast to peroxide treatment of coarse TMP at low alkali charge prior to LCR. The work of Chang et al. [12] showed the possibility of producing a pulp with a higher scattering coefficient at a certain tensile strength compared to control pulp. In that study, the authors indicated that peroxide treatment with lower alkali charge may promote the generation of less-bonding fines or fibrils which contribute more to light scattering coefficient. Hafrén et al.[18] also concluded from their investigation that fines from 2nd and 3rd LC refining stages have much less inter-bonding ability compared with those from 2nd HC refining stage.

A statement could be made here, that both the content and properties of fines would influence pulp's light scattering coefficient. The properties of the fines fraction from different trials should be further investigated.

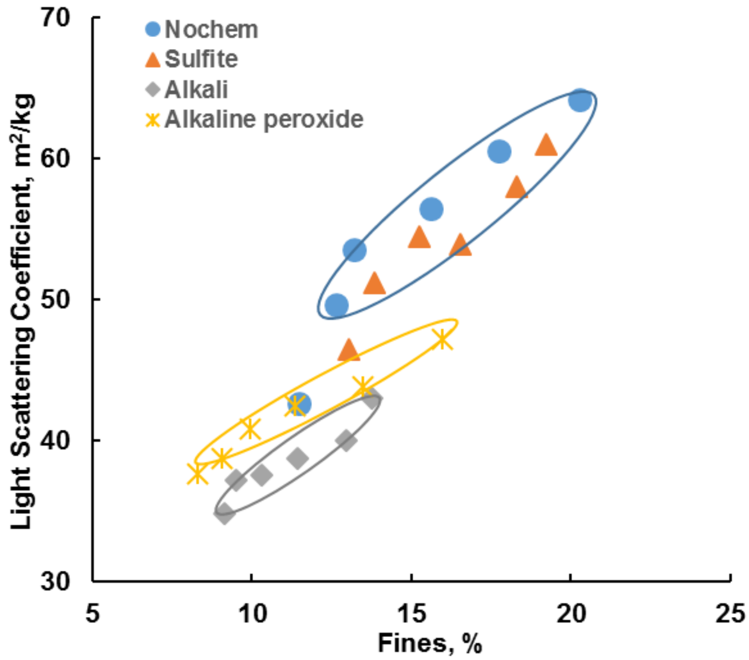


Figure 6 - Correlation between light scattering coefficient and fines content

For mechanical pulps, it's typical that both tensile index and light scattering coefficient increase during the refining process. This is confirmed by results shown in Figure 7. In this study, low consistency refining without chemical pretreatments show significant effect on improving the light scattering coefficient. For the control trial, light scattering coefficient increased from 42 m^2/kg to 64 m^2/kg with the increase of tensile index from 18 N.m/g to 35 N.m/g. For the similar specific energy consumption during LCR, the gain on light scattering for pulp from sulfite trial during LCR is very close to the pulp from control trial. And different correlation between scattering coefficient and tensile index is observed for alkali and alkaline peroxide trials. For these two trials, light scattering coefficient increases slowly with the fast developing of tensile index. As it was discussed previously, compared with control and sulfite trials, pulp from alkaline peroxide trial contain less fines but relative higher average fibre length. Then, it could be concluded here, the significant increase of tensile index of pulp from alkaline peroxide trial should be mainly caused by the better inter-fibre bonding ability of long fibres. Gorski et al [19] found that long fibre fractions of LCR pulp were more flexible compared to the long fibre fraction of HCR pulp at given tensile index. Then, results from this work may suggest that this benefit from LCR could be enlarged by involving alkaline peroxide pre-treatment.

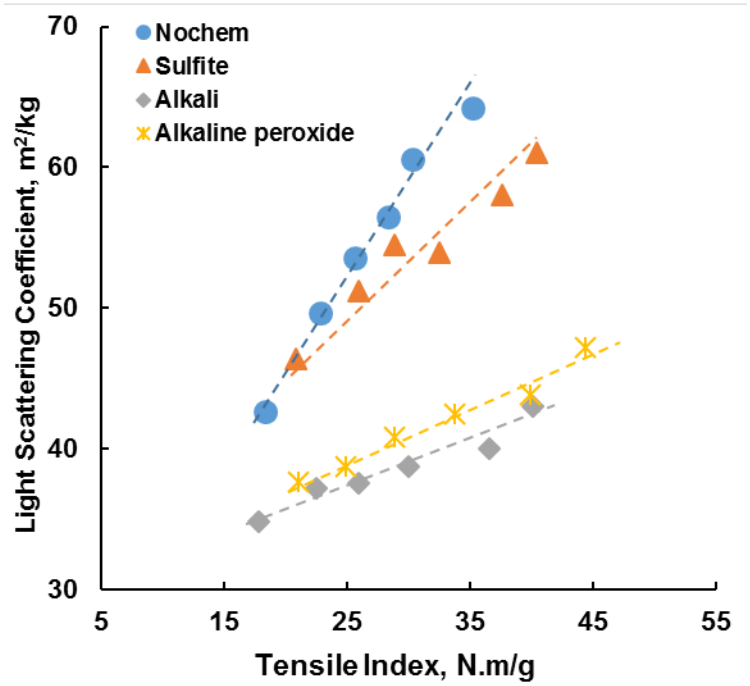


Figure 7 - Correlation between light scattering coefficient and tensile index

Sulphite pre-treatment led to slightly lower light scattering coefficient but higher brightness compared to control trial, seen as in FIGURE After HC refining, pulp from sulfite pre-treated chips had a brightness about 3 % ISO higher than the control. This result is comparable to the effects seen in other research work [7]. Alkaline peroxide treatment of chips was found to lower the pulp brightness compared to control trial. The brightness response of primary and secondary HC refined pulps to alkaline peroxide are different from that of chips. For low freeness HC refined pulp, when 2% H_2O_2 was applied at pH level 13, pulp brightness was 10% ISO higher compared to control pulp [12]. In this study, the pulp darkening during the alkaline peroxide trial is probably caused by the high alkali charge and high temperature during impregnation stage. Wood chips after impregnation stage from alkaline peroxide trial are visibly darker compared with chips from the control and sulfite trial. More research needs to be done on determining the optimal ratio between caustic and alkaline peroxide charge in alkaline peroxide pre-treatment of wood chips to obtain the best brightness and tensile strength. Another observation is that low consistency refining has positive effect on improving brightness for pulps from all trials with or without chemical pretreatment. This enhancement of brightness during LCR is likely related to the generation of fines. About 2 units' brightness was gained for each trial during LCR, as seen in Figure 8.

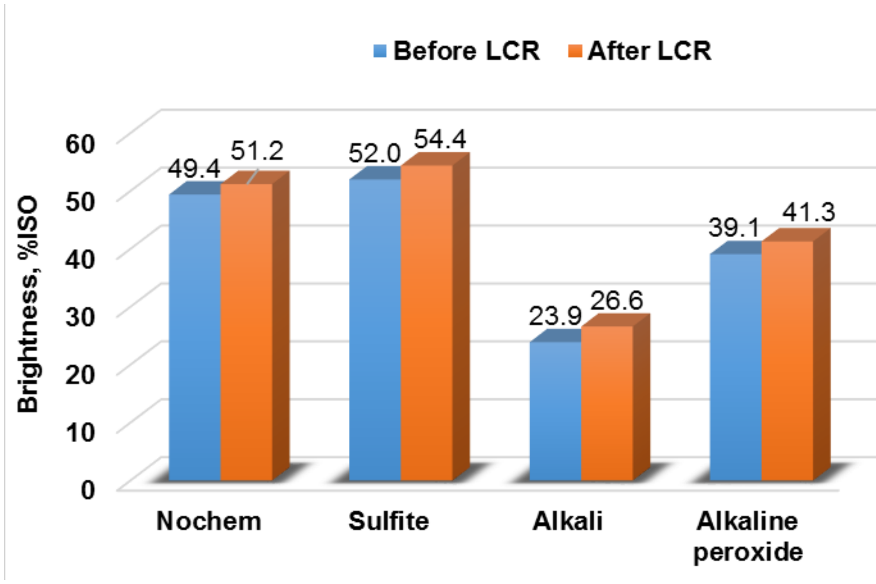


Figure 8 - Effects of different chemical pretreatments of wood chips on brightness, and influence of LC refining on brightness

CONCLUSIONS

Among three different chemical pre-treatments on wood chips, alkaline peroxide shows the most savings in energy in production of pulp at given tensile index. Compared to the control trial, about 24% total refining energy could be saved to produce a pulp at tensile index of 40 N.m/g by applying alkaline peroxide pretreatment during the chip impregnation stage. Compared with control and sulfite trials, alkaline peroxide pretreatment also shows better performance on tear index. However, this pretreatment was found to deteriorate both light scattering coefficient and brightness of pulp. In this study, besides the slight increase of tensile index, the only advantage of using sulfite pretreatment is the gain on brightness. Compared to control trial, chemical pre-treatment of wood chips enhances the fibre developing during LC refining. Under a given specific energy during LCR, higher tensile index was gained when chemical pre-treatment was involved.

Acknowledgements

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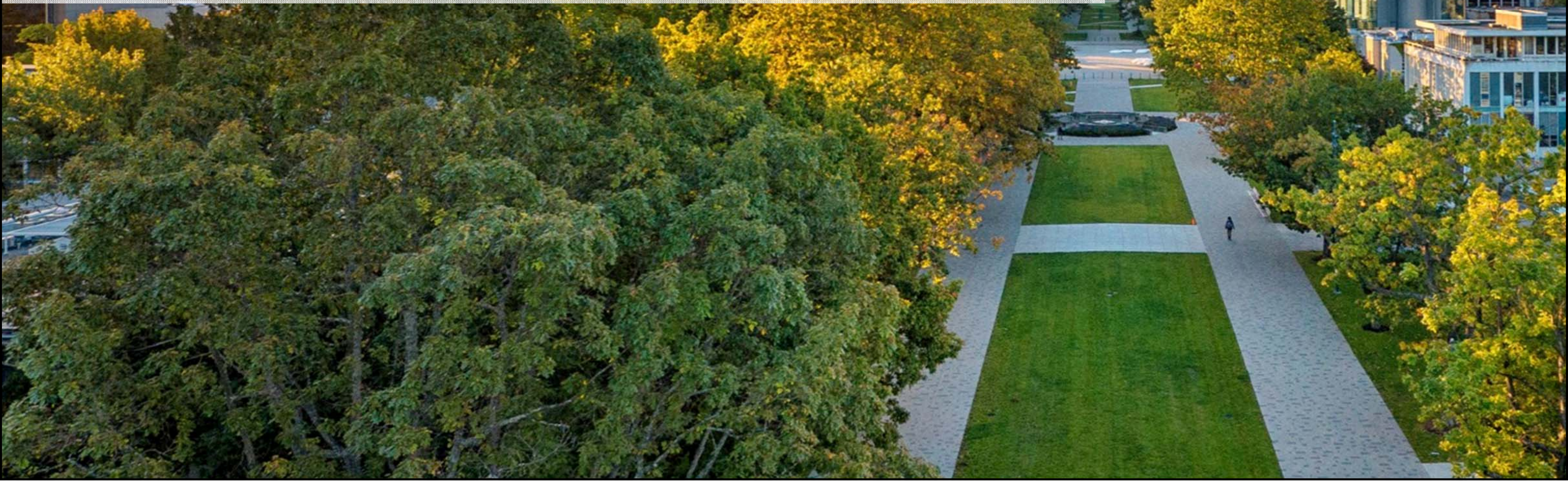

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CONTENTS

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- Results & Discussion
- Conclusions

INTRODUCTION

- √ Sulfite
- √ Alkali
- √ Alkaline peroxide

3

- Pulp freeness: 130mL to 170mL
- Presence of peroxide at high pH
- Higher tensile strength & brightness

Low freeness pulp + Alkaline peroxide + LC refining

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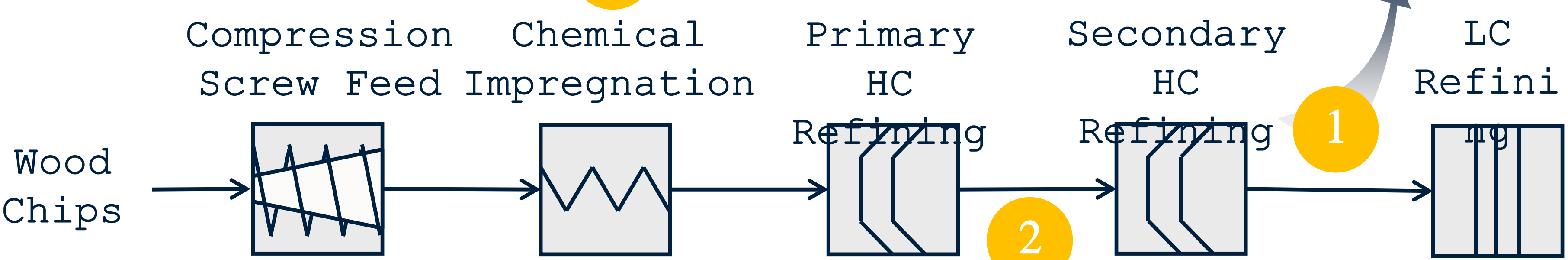
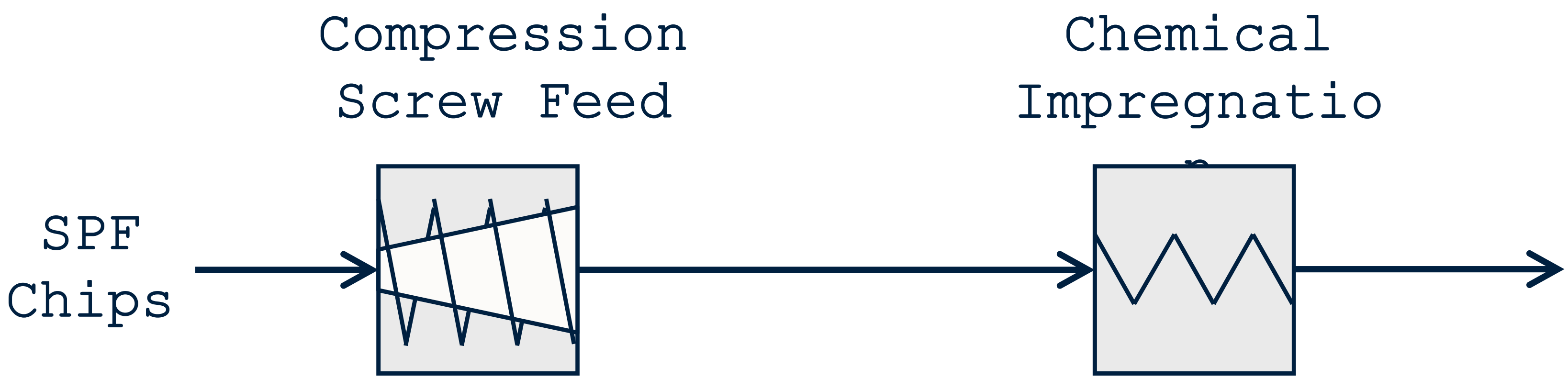


2

High freeness pulp +Alkaline peroxide + LC refining

- Pulp freeness: 380mL to 490mL
- Presence of peroxide at high pH
- 300 kwh/t energy reduction for producing pulps with given tensile strength
- Prevent fibre cutting during LC stage
- Higher brightness

EXPERIMENTAL BACKGROUND



- Steam pressure: 20 p
- Outlet restriction:
- 36 RPM
- Normal feed rate

Chemical Treatment	pH
Water only	–
Na_2SO_3 2.05%	8.4
NaOH 5%	13.3
NaOH 3.9% + H_2O_2 1.8%	13.1

EXPERIMENTAL BACKGROUND

* *36-1CP refiner at 2300 RPM*

	SRE (kWh/OD)	Freeness (mL CSF)
Control	704	573
Na_2SO_3	680	580
NaOH	697	648
$NaOH+H_2O_2$	647	642

- Conducted at PPC
- Parameters of LCR

  Refiner speed: 1200 RP

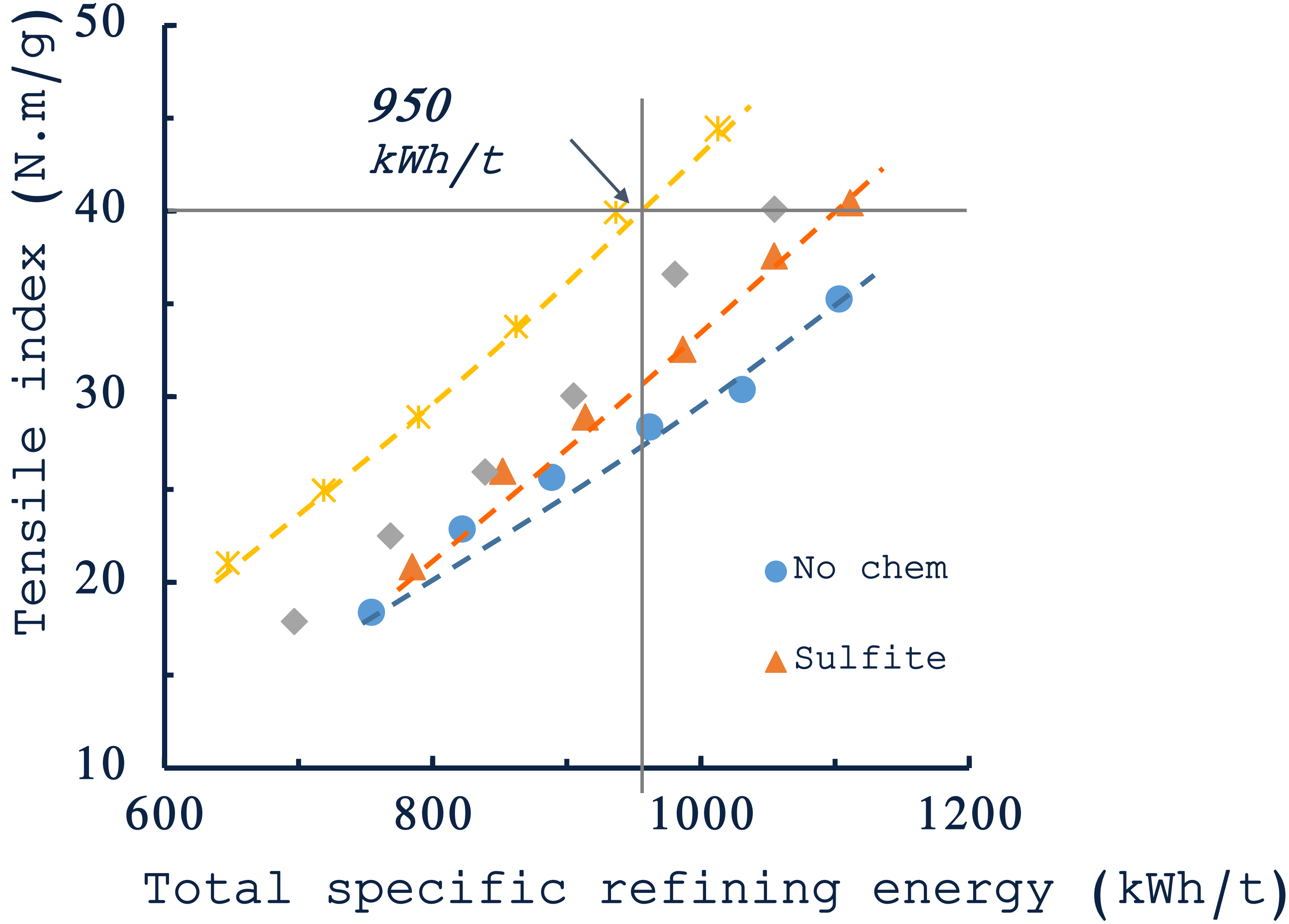
  Flow rate: 250 L/min

  Pulp consistency: 3.5%

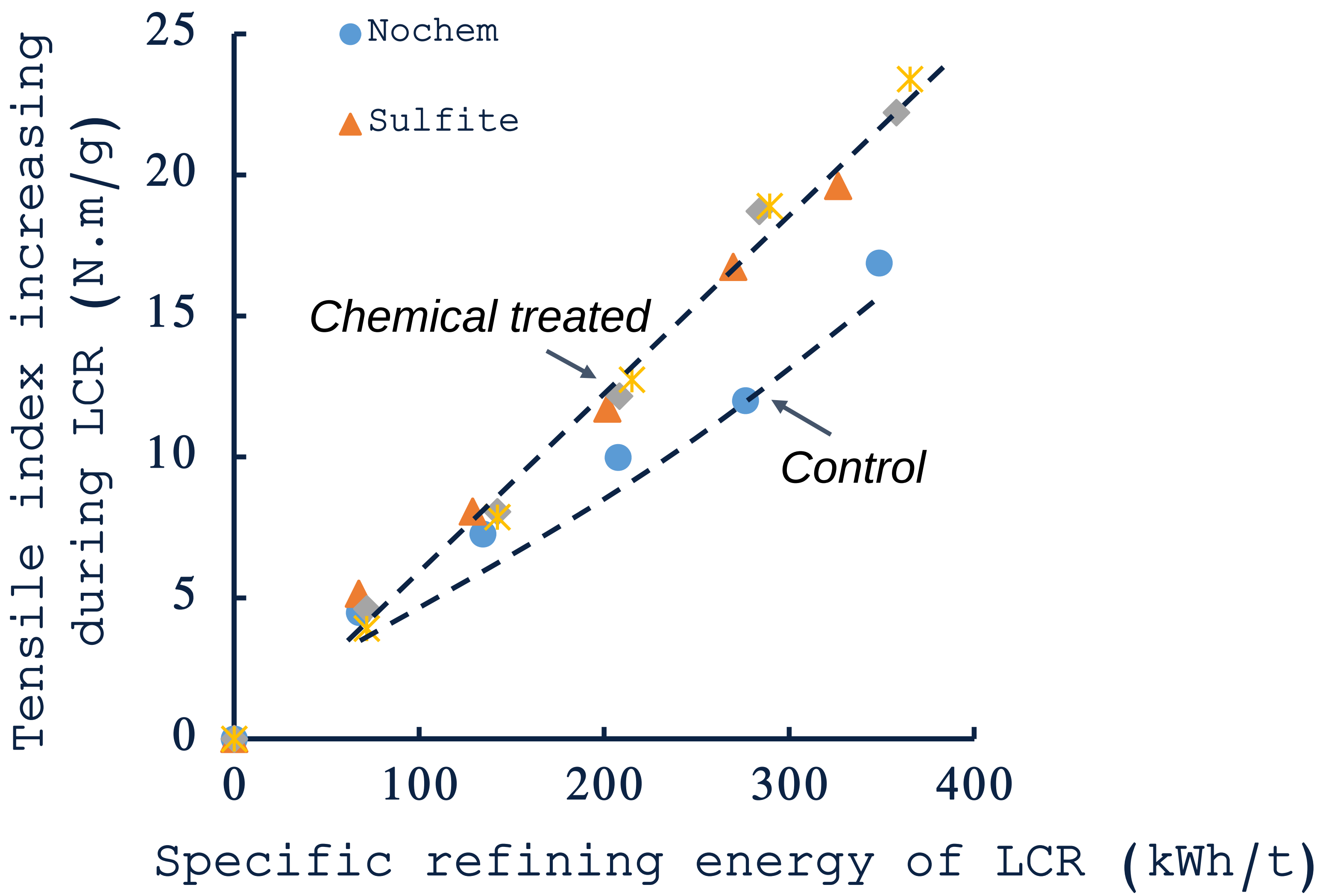
  Target SEL: 0.50 J/m

  Plate BEL: 2.74 km/re

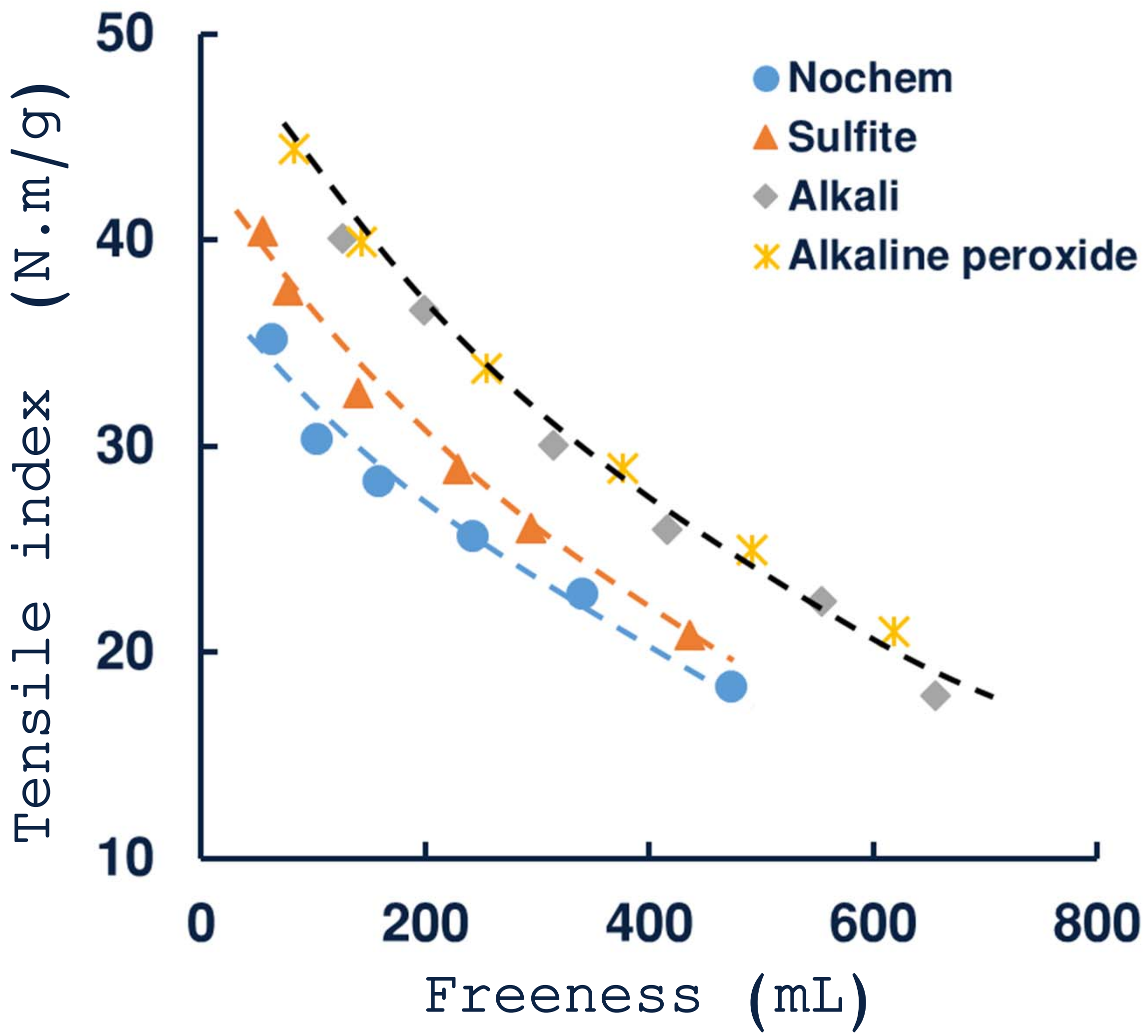
RESULTS & DISCUSSION



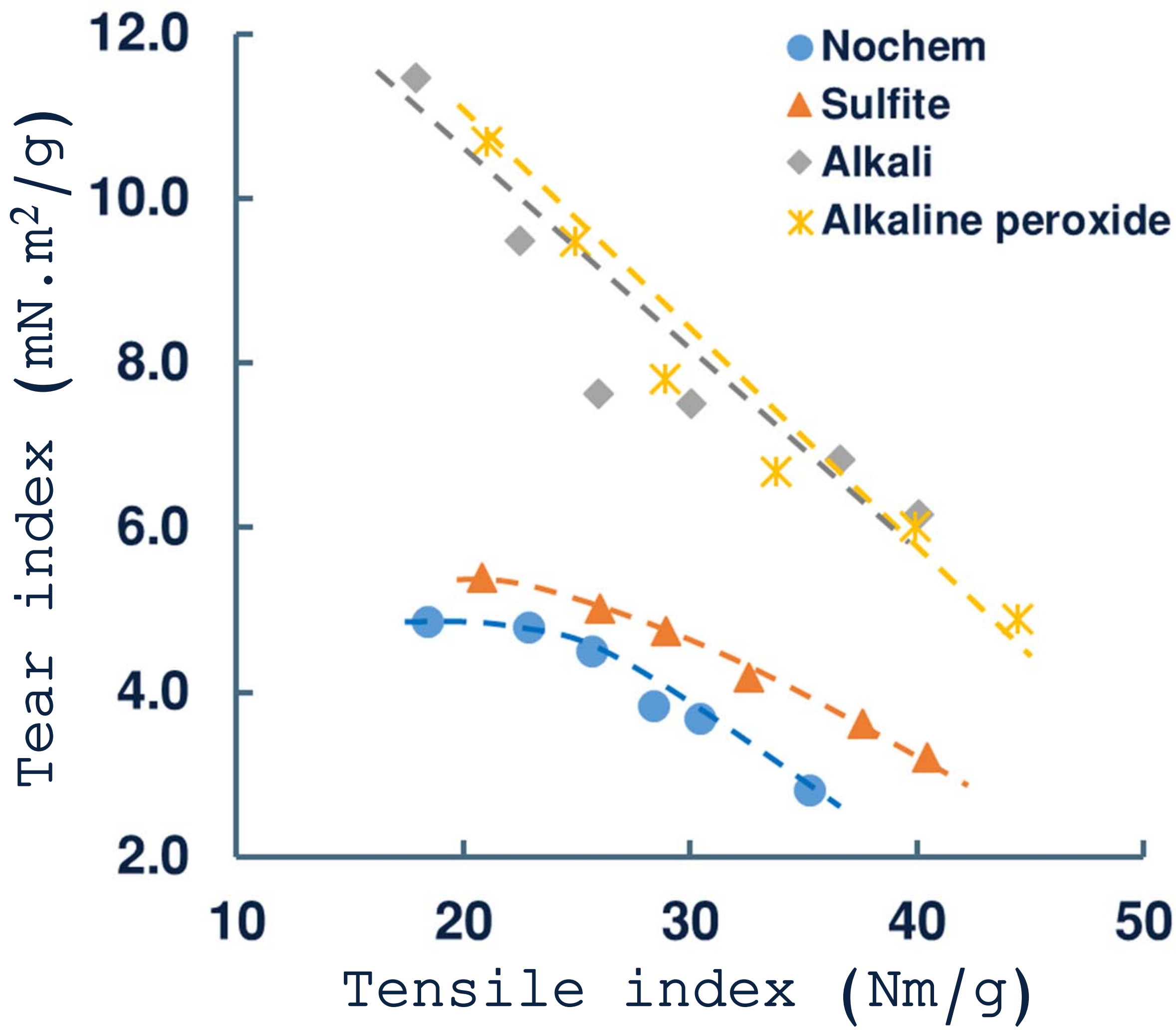
RESULTS & DISCUSSION



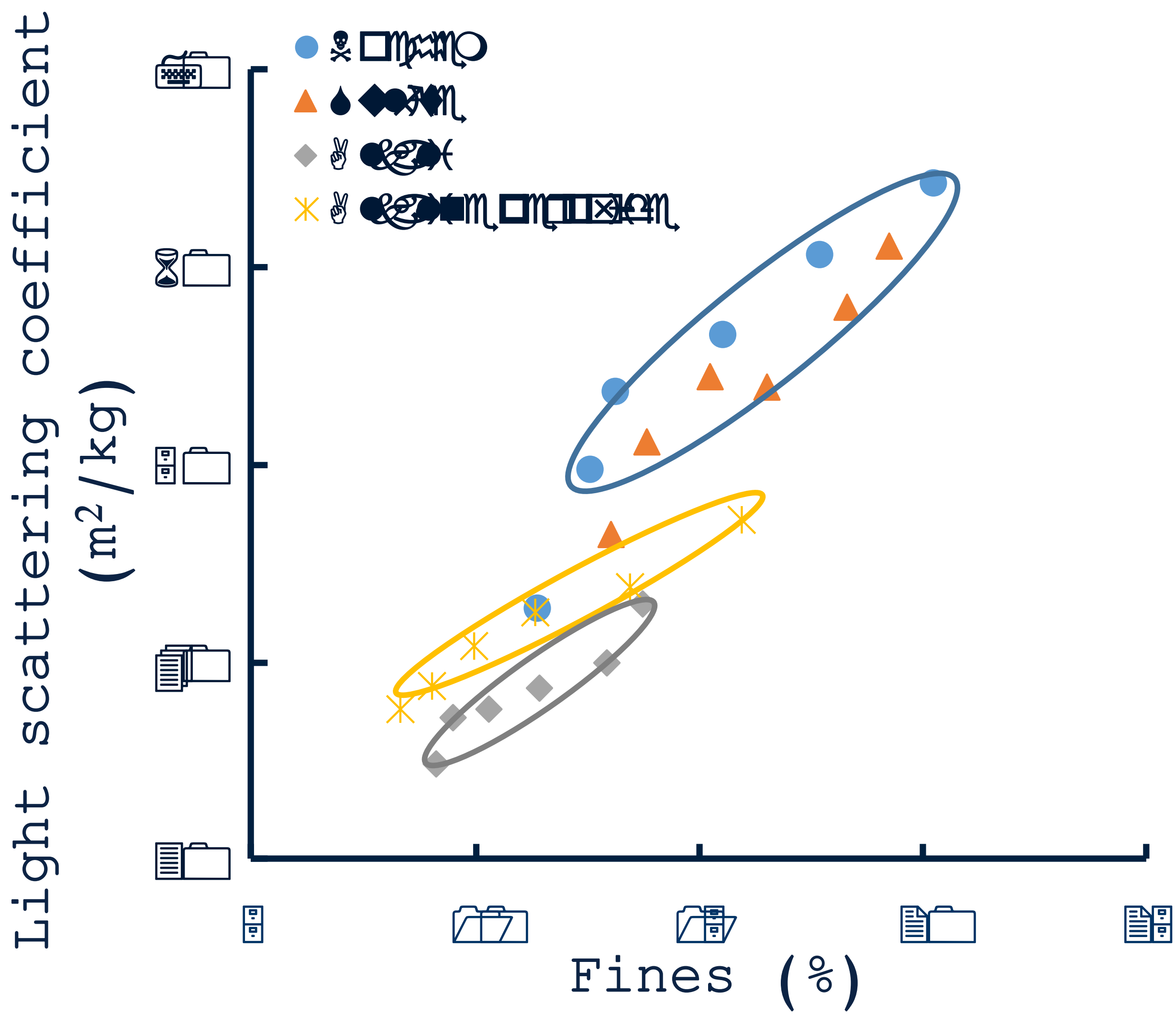
RESULTS & DISCUSSION



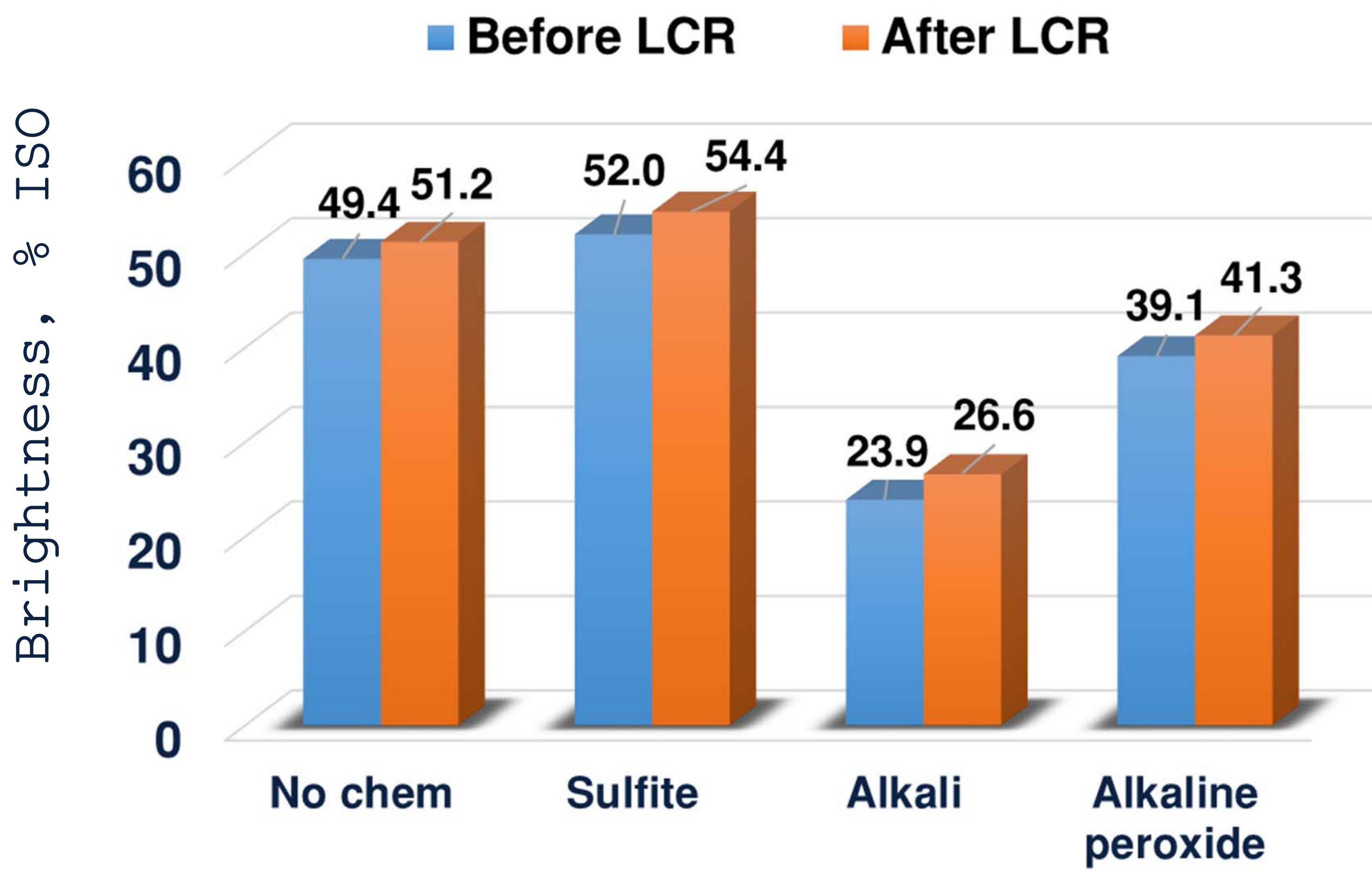
RESULTS & DISCUSSION



RESULTS & DISCUSSION



RESULTS & DISCUSSION



CONCLUSIONS

1. Compared to the control trial, about 24% total refining energy could be saved to produce a pulp at tensile index of 40 Nm/g by applying alkaline peroxide pre-treatment during chip impregnation stage.
2. The main gain in tensile strength through chemical pre-treatments with alkaline peroxide occurs during the HCR.
3. Compared with the control trial, chemical pre-treatment on woodchips promoted tensile gain and fibrillation of fibres during LCR.
4. No obvious difference could be observed in the development of tensile during LCR among the different chemical pre-treatments.

CONCLUSIONS

5. Alkaline pre-treatments decreased light scattering coefficient and brightness compared to control and sulfite pre-treatment.

6. Low consistency refining has positive effect on improving light scattering coefficient and brightness for pulps from all trials with or without chemical pre-treatment.

FUTURE WORK

- Address the darkening issue caused by alkaline treatments
- Understand the impact of chemical treatments on the mechanisms of fibre development during refining

PARTNERSHIP

TMP mills:

- Alberta Newsprint Company
- Canfor Pulp
- Catalyst Paper (3 Mills)
- Holmen Paper
- Millar Western
- Paper Excellence (Meadow Lake Pulp)
- West Fraser (Quesnel River Pulp and Slave Lake Pulp)
- Weyerhaeuser - Norpac
- Winstone Pulp International

Suppliers:

- AB Enzymes
- Andritz
- Aikawa Fibre Technologies
- FPInnovations
- Westcan Engineering

Utilities:

- BC Hydro

Government:

- Natural Sciences and Engineering Research Council

Universities: UBC, University of Victoria, University of Toronto, BCIT


THANK YOU
ANY QUESTIONS ?