Mechanical pulping

Francisco J. Fernandez, D. Mark Martinez and James A. Olson*

Investigation of low consistency reject refining of mechanical pulp for energy savings

https://doi.org/10.1515/npprj-2018-3006
Received August 9, 2017; accepted December 10, 2017; previously published online February 27, 2018 on www.npprj.se

Abstract: In this study, the effects of low consistency refining (LCR) energy and intensity on mechanical pulp properties have been studied for three different types of reject pulps (softwood TMP, softwood CTMP and hardwood CTMP), which were refined at varying intensity. Resulting pulp properties have been compared with high consistency refining (HCR) of the same reject pulps. For all furnish types, it was shown that LCR can develop pulp properties matching those developed through HCR with significantly less energy. The resulting pulp properties were found to be affected not only by refining intensity and energy, but also by initial fibre morphology. Pilot LCR trials demonstrated that high freeness reject pulp is initially insensitive to refining intensity as specific energy is applied. This enables the first stage of LCR to be carried out at a higher specific energy and intensity, which can reduce the number of stages of LCR required to reach a target quality. This work shows that low intensity LCR is capable of achieving the same tensile index as HCR pulp at a target freeness of 200 ml CSF.

Keywords: energy efficiency; hardwood pulps; low consistency refining; refining energy; refining intensity; softwood pulps; thermomechanical pulping; TMP.

Introduction

Low consistency refining (LCR) has the potential to reduce energy consumption of the mechanical pulping process and can achieve certain pulp quality targets with lower energy consumption when compared to high consistency refining (HCR). LCR has been used in TMP mills increasingly since the 1970s, first in tertiary and post-refining (Flowers et al. 1979, Bonham et al. 1983, Vaughn et al. 1998), and more recently in secondary and reject stages of refining in place of HCR (Hammar et al. 1997, Muenster et al. 2006, Eriksen and Hammar 2007, Sabourin 2007, Sandberg et al. 2009, Hammar et al. 2010, Luukkonen et al. 2010, Chang et al. 2011, 2012, Luukkonen 2011, Andersson et al. 2012, Gorski et al. 2012a, 2012b, Elahimehr et al. 2012, Luukkonen et al. 2012, Fernando et al. 2014, Elahimehr et al. 2015, Sandberg et al. 2016).

Previous refining studies of Norway spruce and spruce-pine-fir mix (SPF) primary pulp show energy savings of 20 % when refining to a 40 N m/g tensile index (Eriksen and Hammar 2007, Gorski et al. 2012a). However, LCR was detrimental for other properties including tear and long fibre content. The observed differences are due to the different fibre morphology resulting from the HCR and LCR processes. It is well documented that fibre morphology changes during HCR and LCR can be quite different (for example, in Fernando et al. 2014, Gorski et al. 2012b). LCR is more efficient at internally and externally fibrillating the fibres when compared with HCR. In addition, LCR can produce high axial loads on the fibres that causes them to rupture. It is expected that coarser fibres, like those in the reject stream, are stronger and rupture at a higher load and are therefore able to be refined at higher intensities without being cut. Thus, the potential for energy savings using LCR on long coarse reject fibres is thought to be greater. Indeed, it has been found that increasing the long fibre content will decrease fibre shortening (Andersson et al. 2012).

The work presented here focuses on determining the optimal refining conditions for coarse reject pulp of different feeds (softwood TMP, softwood CTMP and hardwood CTMP) and determining the potential energy savings of LCR for these applications.

Pulp is refined to reduce shives, develop strength, increase densification and improve formation. These properties are developed through various fibre morphology changes. The refiner changes the properties by loading the fibres and performing work. There is a compressive force

***Corresponding author: James A. Olson,** University of British Columbia, Pulp and Paper Centre, 2385 East Mall, Vancouver, Canada, V6T 1Z4, e-mail: james.olson@ubc.ca
Francisco J. Fernandez, Allnorth, 1200-1100 Melville St, Vancouver, Canada, V6E 4A6 (former affiliation: University of British Columbia), e-mail: ffernandez@allnorth.com
D. Mark Martinez, University of British Columbia, Pulp and Paper Centre, 2385 East Mall, Vancouver, Canada, V6T 1Z4, e-mail: mark.martinez@ubc.ca

to maintain the small gap and a shear force as a result of friction. Both forces cause changes in fibre morphology. The shear force delaminates the fibres (external fibrillation) in two ways, generating fines and fibrils, and reducing the fibre wall thickness so that fibres are more flexible. As fibres are delaminated, they become more compressible. The compressive force deforms the fibre, breaking internal bonds (internal fibrillation) and making fibres more collapsible. All mechanisms occur simultaneously in different degrees and have been documented in the literature (Kerekes and Senger 2006, Kerekes 2010, Heymer et al. 2011). Furthermore, other research (Goosen et al. 2007) has shown that refining is a stochastic process. Some fibres can be treated several times in the refiner, while some fibres travel through the refiner grooves without ever being loaded. Thus, there are great challenges in predicting the pulp properties through the refining process.

From the initial work of Brecht (1967) on the Specific Edge Load model to the more recent work by Lumiainen (1990) on the Specific Surface Load model and Kerekes (1990) on the C-factor model, researchers have traced the fibre morphology to refiner operating parameters. It is well known that both refining energy and intensity play a major role in pulp property development. As energy is added to the pulp and bonds are broken, fibres are more flexible, resulting in a higher strength and smoothness. As refining intensity is increased, increased fibre cutting is expected.

In LCR a considerable amount of energy is used to transport the pulp through the refiner and to overcome the hydraulic and mechanical losses of the refiner rotation; known as the "No-Load" power. The No-Load power is measured with the discs 2.5 mm apart with the suspension flowing through the gap. The power applied above this limit is known as the "net refining power" P_{net} and is expended in the form of loading events or bar crossing events, where the pulp is compressed and strained.

SEL represents the energy distribution through the refiner plate (machine intensity). It does not represent the energy distribution throughout the treated pulp (fibre intensity). There are other machine-intensity based factorizations such as specific surface load (SSL) (Lumiainen 1990) as well as fibre-intensity based factorizations such as the C-factor (Kerekes 1990). Roux (2001) also summarized these difference measurements in relation to stock preparation and pulp treatment. However, if consistency is kept constant, an increase of machine intensity will lead to an increase in fibre intensity. In this study, it is not our intention to compare the quality of the different predictors but rather to analyze the difference in pulp response with treatments of varying intensity.

Materials and methods

This study uses furnish from two mills in British Columbia, Canada. Both mills provided long fibre fractions, i. e. screen reject pulp, for LC refining at UBC Pulp and Paper Centre (UBC-PPC) as well as HC refined reject samples for comparison. The softwood TMP reject pulp is hemlock, and the mass reject rate from the mill screening system was close to 25 % and the reject pulp was HC refined to 2100 kWh/t. The hardwood CTMP is aspen and the softwood CTMP is a spruce-pine-fir (SPF) mix from residual chips. The mass reject rate of the mill CTMP pulp screening system was approximately 23 % and was HC refined to 678 kWh/t. The consistency of the pulp provided by the mills was between 32 % and 36 %. Table 1 summarizes the feed furnish properties.

Table 1: Feed Furnish Properties.

Furnish	Species	ml CSF	Fibre Length (mm LW)	Tensile Index (Nm/g)	Bulk (cm^3/g)
SW TMP	Hemlock	550	2.10	27.00	4.10
SW CTMP	Spruce, pine, fir (SPF)	710	1.74	8.03	5.34
HW CTMP	Aspen	715	0.93	5.57	3.83

Table 2: Bar patterns of the 3 Finebar® plates used.

Plate BEL (km/rev)	Bar Width (mm)	Groove Width (mm)	Groove Depth (mm)	Bar Angle
2.01	2.0	3.6	4.8	15°
2.74	1.6	3.2	4.8	15°
5.59	1.0	2.4	4.8	15°

Low consistency refining trials were performed at the UBC-PPC using a 14" Aikawa single disc refiner with 16" overhung Finebar® plates, whose details are shown in Table 2.

For all refining trials, pulp was diluted to about 3 % consistency in hot water (50°C, temperature limited by the municipal water supply to the building).

The pulp was first recirculated through the refiner with plates at open plate gap, a "No Load" sample was taken. The gap was then reduced to meet the target intensity, and samples were taken at determined time periods. The no load power for the refiner was 22.5–27 kW.

Table 3 shows the refining conditions for the trials with the different pulps. The intensity (specific edge load,

Table 3: Refining parameters for low consistency refining trials.

Trial	Pulp	Plate BEL (km/rev)	SEL (J/m)
1	SW TMP	5.59	0.13
2	SW TMP	5.59	0.15
3	SW TMP	5.59	0.43
4	SW TMP	2.74	0.48
5	SW TMP	2.01	0.67
6	SW CTMP	5.59	0.20
7	SW CTMP	2.74	0.22
8	SW CTMP	5.59	**0.34** (0.22-0.39)
9	SW CTMP	5.59	**0.6** (0.4-0.7)
10	HW CTMP	5.59	0.12
11	HW CTMP	5.59	**0.18** (0.19-0.15)
12	HW CTMP	5.59	**0.26** (0.34-0.22)
13	HW CTMP	5.59	0.34
14	HW CTMP	5.59	**0.37** (0.39-0.30)

For all trials, refiner speed was 1200 RPM. Flow rate for TMP trials was maintained at 300 l/min and for CTMP trials, 250 l/min. Bold values of SEL decreased slightly during the trial – mean value given in table and range in brackets.

SEL) values in bold indicate that the target refining intensity was not maintained as the power would decrease at constant gap during refining. Thus, the initial intensity was always somewhat lower than the target intensity.

All pulp testing was performed in the UBC-PPC lab according to TAPPI standards.

Results and discussion

In this section, we include separate sub-figures for each furnish type, each following the convention: (*a*) is softwood thermomechanical pulp (SW TMP), (*b*) is softwood chemi-thermomechanical pulp (SW CTMP), and (*c*) is hardwood chemi-thermomechanical pulp (HW CTMP). The reported intensity shown in the legend of all figures is the energy weighted intensity, calculated by weighting the intensity of each stage by the net specific energy added at that intensity. Each figure also includes the comparative HC refined mill sample.

Trials and data collection took place in 2013 and 2014. While shives were not originally part of the scope of the trial design, the authors acknowledge that shive data would have been helpful to extend the data analysis. Unfortunately at the time of the trials, the UBC Pulp and Paper Centre lab did not have a shive analyser in order to take these measurements.

Figure 1 shows the freeness versus specific energy consumption (SEC_{Net}) for all trials. Figure 1a shows that a considerable amount of energy (approximately 200 kWh/t)

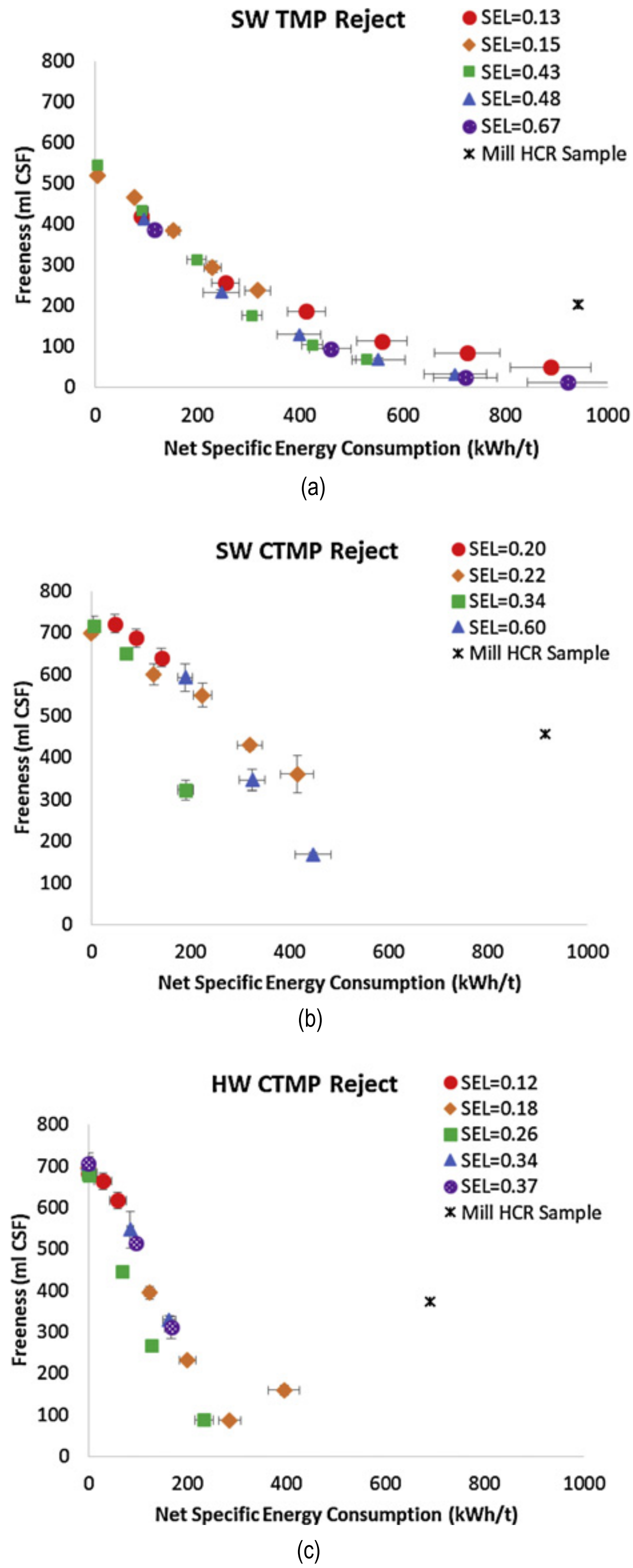

Figure 1: Freeness response against net specific energy consumption for the various feeds and refining intensities.

can be added to the SW TMP pulp at different intensities and result in a similar freeness drop. After 200 kWh/t, high intensity treatments lead to lower freeness values when compared to the same energy.

A similar behavior is found for the SW CTMP pulp in Figure 1b. It is hypothesized that this is because prior to refining, fibres are coarse and strong enough to withstand high intensity refining. We suggest that after being refined, fibre coarseness is reduced and fibres become weaker and subsequent refining at high intensity causes the fibres to rupture, whereas low intensity leads to fibre fibrillation.

In the case of HW CTMP in Figure 1c, there was no observed range where freeness was independent of intensity. It is possible that this is not the case for higher refining intensity values (greater than 0.4 J/m) or for very low intensities (less than 0.2 J/m). The use of ultra-low intensity refining of HW CTMP is the subject of future investigations. Higher intensity values were not possible to obtain given the loadability of the pulp and the bar pattern of the plate used.

Figure 2 shows tensile index development for the different reject pulps. In the case of SW TMP (Figure 2a), refining intensity in the range tested is not an important factor when refining to a given freeness value. Similar behavior can be found for the SW CTMP pulp in Figure 2b. In the case of the HW CTMP pulp, Figure 2c shows that lower intensity refining (SEL of 0.26 J/m or lower) is capable of achieving a better tensile development than HC refining at a target freeness.

In the previous section, we saw that hemlock (SW TMP) required less energy than SPF (SW CTMP) to refine to a given freeness. Moreover, Figure 2 shows that the tensile index developed when compared to the same freeness is much higher for hemlock, SW TMP than for SPF, SW CTMP (52 Nm/g vs 30 Nm/g at 200 ml CSF). Figure 2 also shows that even though aspen (HW CTMP) shows the fastest freeness drop with energy, it does not develop as much strength. Furthermore, HW has a lower starting fibre length (0.9 mm vs 2.1 mm), which also contributes to the lower strength.

Lastly, both Figure 1 and Figure 2 show that significant energy savings without losses in quality are achievable with low consistency refining. Low intensity LC refining of SW TMP is capable of reducing the net specific energy from 1000 kWh/t (with HC refining) to 400 kWh/t. For SW CTMP and HW CTMP, the required net specific energy is reduced from 900 kWh/t to 300 kWh/t and from 680 kWh/t to 180 kWh/t, respectively. Low consistency refining is thus capable of reducing the load on SW reject refining by 60 % of the net specific energy added through

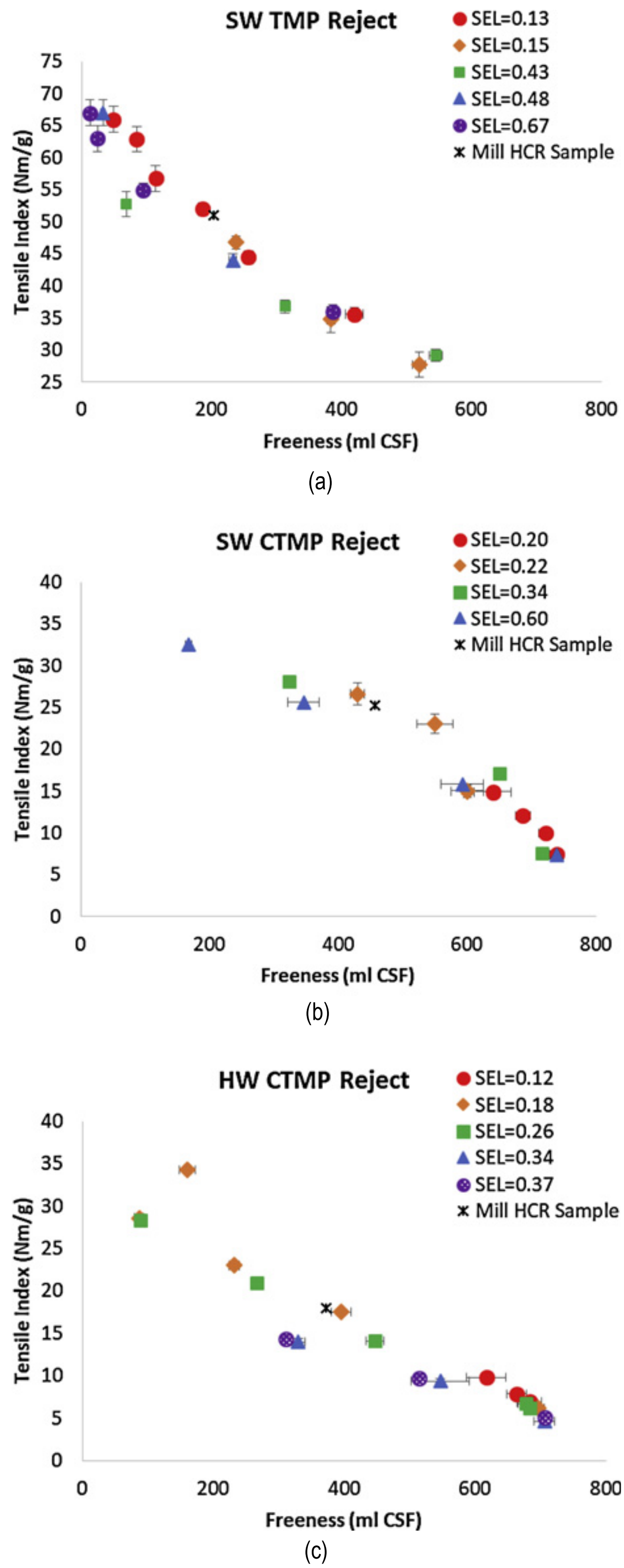

Figure 2: Tensile index development as freeness is lowered through different intensity refining for different feed pulps.

high consistency refining. This equates to 6.5 % of the total net refining energy at a mass reject rate of 25 %.

In order to provide insight to the underlying mechanisms of refining, the average fibre length and per cent fines were also measured, as shown in Figure 3 and Figure 4, respectively (note that data is not available for all samples). Fines are defined as fibres of length less than 0.2 mm.

As can be seen in Figure 3a, low intensity refining preserves the fibre length as energy is added to the pulp. Furthermore, for the initial energy range (less than 200 kWh/t) it is observed that even high intensity does not result in significant fibre cutting. Beyond this threshold, high intensity treatments yield shorter fibres. Figure 3b shows that it is slightly more difficult to preserve length in SPF, SW CTMP, through refining than with hemlock (SW TMP, Figure 3a). This was the opposite of what we expected. The higher coarseness of SPF should result in a stronger fibre against rupture. Nevertheless, the shorter length may be due to the heterogeneity of the furnish as the longer fibres in the SPF mix do not necessarily have the highest coarseness. Figure 3c shows that the aspen (HW CTMP) does not maintain its length even with low intensity treatments. Although the aspen is thick-walled compared to its width, it has a low coarseness and thus a low strength towards rupture.

From Figure 4, we can deduce that initially, refining develops strength by generating fines. Initially, these fines do not come from cutting the fibres since Figure 3 shows that fibre length is preserved, but from external delamination of the fibre wall. Beyond the threshold, high intensity refining continues to generate fines, at a significantly faster rate than low intensity refining. The difference is that these fines are actually the result of fibre cutting.

The results of this study show that the development of reject pulp properties can be explained by three dominating mechanisms: abrasion leading to external fibrillation and higher flexibility; compression leading to internal fibrillation and higher flexibility; and friction causing an axial force the can lead to fibre cutting. It is believed that these mechanisms of pulp property development of the LC reject refined pulp are somewhat sequential and change as fibres become further refined. Since reject fibres are initially rigid and coarse they have a higher resistance toward compression and internal fibrillation. Thus, they are initially de-coarsed by the abrasion mechanism of low consistency refining. The amount of material removal (generated fines) is known to be related to the amount of energy added in the form of work of the shearing force acting on the fibres (Kerekes 2010). This initial fines generation is not the result of intensity but of work provided by the shear

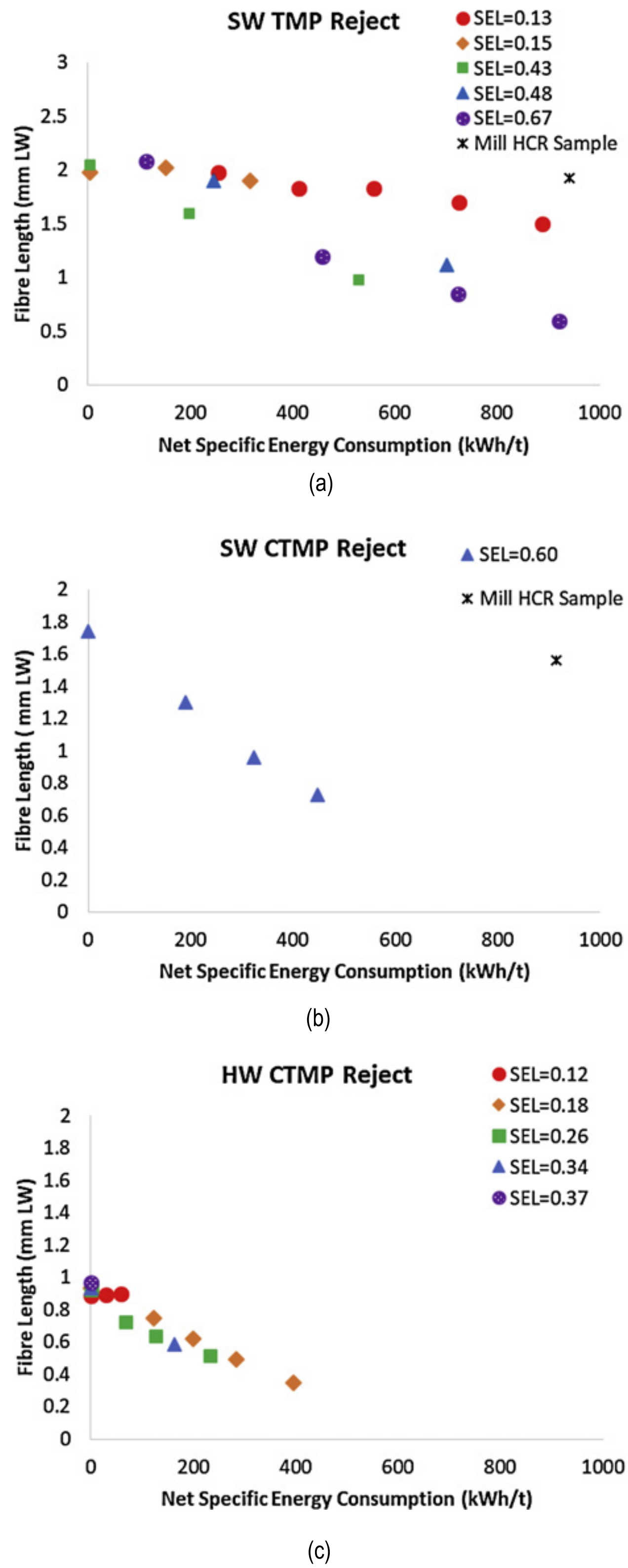

Figure 3: Fibre length preservation as energy is added to the different types of reject pulps.

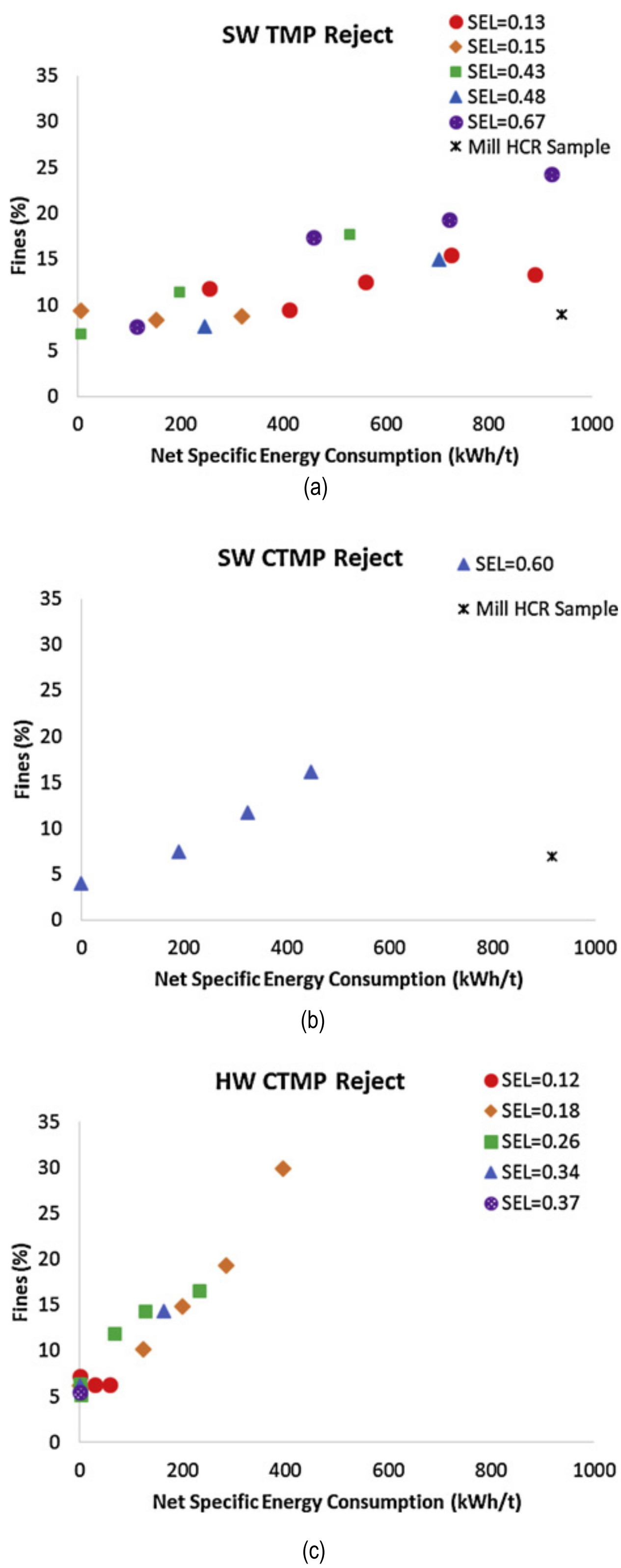

Figure 4: Fines generation as energy is added to the different types of reject pulps.

force on the fibre. This explains the high degree of correlation between energy and property development during the first range of energy. As fibres become less coarse, they become more flexible and offer less resistance for compression. This leads to internal fibrillation which continues to develop strength. Nevertheless, since fibres are less coarse they are also prone to being ruptured by the axial loads leading to fibre cutting. This explains why in some cases, tensile index continues to be developed while length is shortened. By decreasing the force, fibres can continue to be developed through external fibrillation without being cut.

Conclusions

This pilot study investigated the effect of low consistency refining conditions on the pulp property development of long fibre (reject) TMP. In this study, it has been found that low consistency refining is capable of reducing the load on softwood reject refining by 60 % of the net specific energy added through high consistency refining. This equates to 6.5 % of the total net specific refining energy at a mass reject rate of 25 %.

In order to achieve pulp properties similar to HC refining, the pulp must be refined at low intensity after the threshold where the fibres have been fibrillated to the point that they are weak to resist the axial loads. Thus, when determining the optimal intensity, it is important to consider not only the pulp furnish and length but also the starting freeness prior to refining.

Acknowledgments: The authors would like to acknowledge UBC Pulp and Paper Centre members Marion Loubet, Emilia Jahangir and Christine Saville for the pulp preparation and testing, and Nici Darychuk and George Soong for the execution of the numerous refining trials. Meaghan Miller assisted in final manuscript preparation and revisions. Special thanks to Scott Shannon of Millar Western Forest Products, Dr Taegeun Kang (while at Howe Sound Pulp and Paper Corporation) and Dr Richard Kerekes for their support and valuable input.

Funding: This research was conducted as part of the Energy Reduction in Mechanical Pulping program, which is funded by a Collaborative Research and Development grant provided by National Sciences and Engineering Research Council of Canada (NSERC) and the following partners, who we thank for their ongoing support: AB Enzymes, Alberta Newsprint Company, Andritz, BC Hydro, Canfor Pulp, Catalyst Paper, FPInnovations, Holmen Paper, Meadow Lake Pulp (Paper Excellence), Millar Western, NORPAC, West Fraser, Westcan Engineering, and Winstone Pulp International.

Conflict of interest statement: The authors do not have any conflicts of interest to declare.

References

Andersson, S., Sandberg, C., Engstrand, P. (2012) Effect of long fibre concentration on low consistency refining of mechanical pulp. Nord. Pulp Pap. Res. J. 27(4):702–706.
Bonham, J.S., Flowers, A.G., and Schofield, A.J. (1983) Post refining of radiata TMP. Appita J. 36(6):466–470.
Brecht, W. (1967) Method for comparative evaluation of bar-equipped beating devices. Tappi 50(8):40–44.
Chang, X.F., Bridges, C., Yu, D., Kuan, D., Kuang, L., Olson, J.A., Luukkonen, A., Beatson, R.P. (2011) Saving electrical energy by alkaline peroxide pretreatment of TMP prior to low consistency refining. PAPTAC Peer-Rev. Tech. Pap., July–August 2011 Issue.
Chang, X.F., Olson, J.A., Beatson, R.P. (2012) A comparison between the effects of ozone and alkaline peroxide treatments on TMP properties and subsequent low consistency refining. BioResources 7(1):99–111.
Elahimehr, A., Olson, J.A., Martinez, D.M. (2015) Low consistency refining of mechanical pulp: How plate pattern and refiner operating conditions change the final properties of pulp. Nord. Pulp Pap. Res. J. 30(04):609–616.
Elahimehr, A., Olson, J.A., Martinez, D.M., Heymer, J. (2012) Estimating the area and number of bar crossings between refiner plates. Nord. Pulp Pap. Res. J. 27(5):836–843.
Eriksen, O., Hammar, L.A. (2007) Refining mechanisms and development of TMP properties in a low-consistency refiner. In: Int. Mech. Pulp. Conf., Minneapolis, MN, USA, June 7–9, 2007. TAPPI Press, Norcross, GA, USA. pp. 62–75.
Fernando, D., Gorski, D., Sabourin, M., Daniel, G. (2014) Characterization of fiber development in high- and low-consistency refining of primary mechanical pulp. Holzforschung 67(7):735–745.
Flowers, A.G., Pearson, A.J., and Tyler, A.G. (1979) A preliminary report on single stage TMP pulping of P. radiata followed by post refining. Appita J. 33(3):195–200.
Goosen, D.R., Olson, J.A., Kerekes, R.J. (2007) The role of heterogeneity in compression refining. J. Pulp Pap. Sci. 33(2):110–114.
Gorski, D., Luukkonen, A., Sabourin, M., Olson, J.A. (2012a) Two-stage low-consistency refining of mechanical pulp. Appita J. 65(3):244–249.
Gorski, D., Mörseburg, K., Olson, J.A., Luukkonen, A. (2012b) Fibre and fines quality development in pilot scale high and low consistency refining of ATMP. Nord. Pulp Pap. Res. J. 27(5):872–881.
Hammar, L.A., Htun, M., Svensson, B. (1997) Two-stage refining process to save energy for mechanical pulps. In: Int. Mech. Pulp. Conf., Stockholm, Sweden, June 9–13, 1997. SPCI, Stockholm, Sweden. pp. 257–261.
Hammar, L.Å., Salmén, L., Sandberg, C., and Sundström, L. (2010) The effect of process conditions on pulp quality development in low consistency refining of mechanical pulp – TMP. Appita J. 63(5):377–380.
Heymer, J., Olson, J.A., Kerekes, R.J. (2011) The role of multiple loading cycles on pulp in refiners. Nord. Pulp Pap. Res. J. 26(3):283–287.
Kerekes, R.J. (1990) Characterization of pulp refiners by a C-factor. Nord. Pulp Pap. Res. J. 5(1):003–008.
Kerekes, R.J. (2010) Energy and forces in refining. J. Pulp Pap. Sci. 36(1–2):10–15.
Kerekes, R.J., Senger, J.J. (2006) Characterizing refining action in low-consistency refiners by forces on fibres. J. Pulp Pap. Sci. 32(1):1–8.
Lumiainen, J. (1990) New theory can improve practice. PPI Pulp Pap. Int. 32(8):46–47, 54.
Luukkonen, A. (2011) Development of a methodology to optimize low consistency refining of mechanical pulp. Ph.D. Thesis, University of British Columbia, Vancouver, BC, Canada.
Luukkonen, A., Olson, J.A., Martinez, D.M. (2010) Low consistency refining of mechanical pulp, effect of gap, speed and power. J. Pulp Pap. Sci. 36(1–2):28–34.
Luukkonen, A., Olson, J.A., Martinez, D.M. (2012) Low consistency refining of mechanical pulp: Relationships between refiner operating conditions and pulp properties. Nord. Pulp Pap. Res. J. 27(5):882–885.
Muenster, H., Ferritsius, O., Lecourt, M., and Petit-Conil, M. (2006) High temperature LC/MC refining offers TMP energy advantages. In: RISI Pulp Pap., July 2006. pp. 44–49.
Roux, J.C. (2001) Stock preparation part 1 – Pulp treatment processes. In: Sci. Pap., 12th Fund. Res. Symp., Oxford, England, September 17–21, 2001. Ed. Baker, C.F. FRC, London, England. pp. 19–80.
Sabourin, M. (2007) Minimizing TMP energy consumption using a combination of chip pre-treatment, RTS and multiple stage low consistency refining. In: Int. Mech. Pulp. Conf., Minneapolis, MN, USA, June 7–9, 2007. TAPPI Press, Norcross, GA, USA. pp. 839–893.
Sandberg, C., Engstrand, P., and Berg, J.E. (2016) System aspects on low consistency refining of mechanical pulp. In: Int. Mech. Pulp. Conf. (IMPC) 2016, Jacksonville, FL, USA. TAPPI Press, Norcross, GA, USA, pp. 167–177.
Sandberg, C., Sundström, L., Nilsson, L. (2009) Potential of low consistency refining of TMP – Mill evaluation. In: Int. Mech. Pulp. Conf., Sundsvall, Sweden, May 31–June 4, 2009. SPCI, Stockholm, Sweden. pp. 186–189.
Vaughn, J.W., Mitchell, G.W., Musselman, R.L. (1998) Third stage, low consistency refining of TMP mill experience on southern pine. In: Int. Mech. Pulp. Conf., Montreal, Canada, October 25–29, 1998. TAPPI Press, Norcross, GA, USA, pp. 379–390.