Energy saving potential of interstage screen fractionation for production of board grade BCTMP

QUANQING ZHA, REZA AMIRI, AND ZHIRUN YUAN

ABSTRACT: Over the last few decades, the continuing decline in mechanical pulp-based grades has led pulp producers to modify operations and implement measures to reduce production costs in order to stay competitive. In spite of a considerable effort to reduce energy consumption, the latter is still a major portion of production costs in the process of making bleached chemithermomechanical pulp (BCTMP). In this study, we evaluated the impact of interstage screening fractionation (ISSF) and secondary refining strategy for producing BCTMP with the objective of reducing refining energy consumption while maintaining or improving bulk and strength properties.

In the first step and to establish a baseline for a mill's existing configuration, the collected primary refined pulp and reject streams from the ISSF were refined in a high consistency (HC) refiner to target freeness levels. The accepts and refined rejects streams were recombined, and their properties were compared to those of the refined primary pulp. The results showed that, at a given freeness of 400 mL and compared to the control case (without fractionation), the ISSF using an 0.070 in. basket followed by rejects refining could lead to about 25% energy saving in the second stage HC refining. Handsheet properties showed that utilization of ISSF could produce BCTMP with higher bulk and similar average fiber length and tear index. However, a slight reduction in tensile strength was observed.

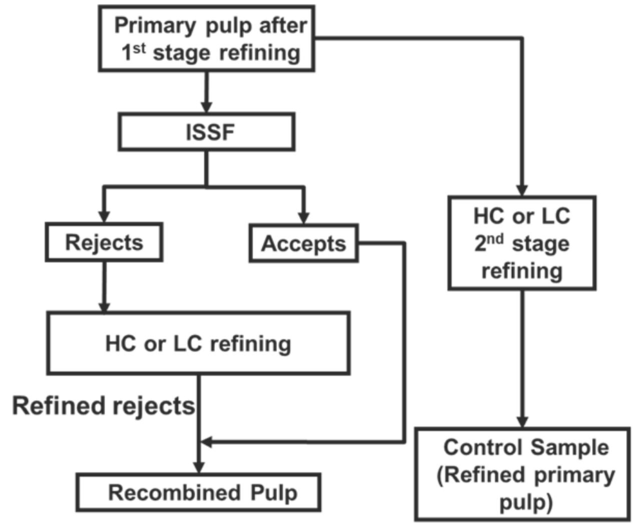
In the second set of trials, the primary refined pulp and the rejects from the ISSF using the 0.070 in. basket were refined by a low-consistency (LC) refiner. The results showed that, at the same freeness of 400 mL and compared to refined primary pulp, the ISSF saved about 26% in net LC refining energy. At a specific edge load (SEL) of 0.4 J/m, the produced pulp had similar bulk and strength properties compared to those of the control sample. A higher SEL of 0.6 J/m in LC refining could further decrease net refining energy consumption; however, it also led to reduction in fiber length, bulk, and strength properties.

Application: With these findings, BCTMP mills can implement different strategies to produce low-energy, low-carbon BCTMP, with better understanding of the impact of mainline interstage screening fractionation and rejects refining on refining energy reduction and development of pulp properties.

With increasing electricity prices, manufacturing operations that rely on this source of energy have been exploring strategies to maximize energy efficiency in their process. In mechanical pulping, refining of raw material is the most energy intensive stage of the process. This stage represents 35%–40% and 20%–22% of the total production cost in thermomechanical pulping (TMP) and bleached chemithermomechanical pulping (BCTMP,) respectively [1,2].

Wood fiber morphology plays an important role in performance of refining and development of mechanical pulp with different properties [3-6]. Pulp fractionation based on fiber morphological characteristics (e.g., fiber length, fiber wall thickness, etc.) have been studied for many years [7-9]. Over the past few years, mainline interstage screening fractionation (ISSF) combined with rejects refining has attracted increasing attention by researchers and practitioners as a new strategy to reduce refining energy consumption while maintaining adequate pulp properties in producing TMP for various applications [10-12].

In the process of mechanical pulping, mainline refined pulp is sent to the screening process. The screening process consists of one or more stages of fiber fractionation in which longer and less developed fibers, as well as shives, are removed for further refining in rejects refiners. In conventional BCTMP production, screening is conducted on the second stage refined pulp using screen baskets with narrow slots to remove shives and undeveloped long fibers. The mass reject rate is usually about 20%–30%. In our ISSF study, a pressure screen equipped with a smooth profile round hole basket was used to separate primary BCTMP pulp after first stage refining at higher mass reject rates of 40%–80%. Compared to slotted screen baskets, round-hole baskets have been shown to be more efficient in fractionating based on fiber length. This allowed us to separate primary refined pulp into long fibers and fines fractions. After screening, the fines fraction did not need any further refining treatment and therefore was sent forward, while the long fiber fraction was further refined. For the control case, the primary



1. Experimental design (ISSF = interstage screening fractionation; HC = high consistency; LC = low consistency).

pulp was also refined in a high consistency (HC) refiner to target freeness values.

High consistency refining (HCR) and low consistency refining (LCR), and their impacts on pulp properties, have extensively been studied by several researchers [13,14]. While HCR can produce well developed and fibrillated fibers, it would require more refining energy to reach the same freeness when compared to LCR. Therefore, LCR could offer a potential way to reduce refining energy if fiber shortening is minimized during the process [15]. In this study, we also evaluated the effect of screening operating parameters (basket aperture size, mass reject rate) on fractionation efficiency, rejects refining energy consumption (LCR and HCR), and pulp properties.

EXPERIMENTAL SETUP

Figure 1 shows the design of experiments in the pilot plant at FPInnovations in Pointe-Claire, QC, Canada. Primary refined pulp from a Canadian BCTMP mill was shipped to FPInnovations, and screening trials using different screen baskets at different mass reject rates were conducted. Screen rejects were further refined using both HCR and LCR. Accepts of the screening stage were recombined with refined rejects to produce the final pulps. For comparison, primary pulp was also refined in a second stage HCR and LCR using the same conditions as those of the rejects refining.

Pulp samples

The pulp samples used in this study were collected from a Western Canadian BCTMP mill after the first stage of refining in the process (primary pulp at about 650 mL CSF). Wood species were a blend of white spruce (20%), lodgepole pine (60%), Douglas fir (15%), and balsam fir (5%). The primary refined pulp was shipped to the FPInnovations pilot plant in Pointe-Claire, QC, Canada, for refining and screening trials.

Fractionation

Screen fractionation trials were performed using a Hooper PSV 2100 pressure screen equipped with a rotor with

2. Hooper PSV 2100 pressure screen.

3. Hooper rotor with blades.

4. Bauer 400 double-disc refiner.

5. Escher Wyss R1L laboratory refiner.

blades and using smooth profile round-hole baskets (**Fig. 2**). Three screen baskets with different hole sizes were used in the trials: 0.060 in., 0.070 in., and 0.085 in. hole diameters. Rotor (**Fig. 3**) speed was about 1300 rpm. Feed pulp at 1.2%–1.4% consistency was disintegrated at 70°C for 45 min in the main tank prior to screening in order to ensure adequate removal of latency. Feed pressure and flow were in the range of 110–130 kPa and 1000 L/min, respectively.

The impact of mass reject rate (RRw) on screen performance was studied by changing the screening rejects rate from 30% to 90%. We determined that the optimized RRw was about 60%–70%. After each fractionation run, samples of screen rejects and accepts were collected for further evaluation and testing.

Refining

Collected screen rejects were refined in HC and LC refiners. The HC refining trials were conducted in an atmospheric 36 in. Bauer 400 double-disc refiner at 1200 rpm and 25%–30% consistency (**Fig. 4**). The LC refining trials were done in a laboratory Escher Wyss R1L refiner running at 1000 rpm (**Fig. 5**). Pulp samples were refined in multiple passes (8 L/min flow rate) at 3%–3.5% consistency to reach the target freeness level at constant target specific edge loads (SELs) of 0.4 J/m and 0.6 J/m, respectively.

The rejects were refined to several freeness levels covering a wide range of 350 to 550 mL CSF. Screen accepts were recombined with refined rejects according to the RRw to produce the final furnish (recombined pulp). For comparison purposes, primary pulp was also refined under the same conditions as those in reject refining trials in both HCR and LCR. Then, PAPTAC Standards were used to prepare and test pulp and handsheet properties. Fiber length was measured using the fiber quality analyzer (FQA) instrument, FQA LDA02 (OpTest Equipment Inc.; Hawkesbury, ON, Canada), and it was expressed as length weighted average fiber length (Lw).

RESULTS AND DISCUSSION

Fractionation analysis

Table I shows pulp properties of screen feed, accepts, and rejects before and after fractionation. Screen feed freeness and consistency for the ISSF trials with different size baskets were about 660–670 mL and 1.2%–1.4% respectively.

As expected, compared to rejects, the accepts pulp had lower long fiber and significantly more fines content, resulting in lower freeness. The basket opening size has a significant impact on the screen long fiber removal efficiency. Reducing basket aperture diameter would lead to an increase in long fiber removal efficiency. The results in Table I confirm that the lowest amount of long fiber (R28) and highest fine content (P200) were obtained for accept pulps

Fractionation	Input – Output	Consistency, %	CSF, mL	Bauer McNett, %		T_R	RRw, %
				R28	P200		
0.060 in. screen basket	Feed	1.4	673	47.5	14.7	2.3	68
	Rejects	3.1	730	56.3	7.7		
	Accepts	0.4	159	15.4	41.6		
0.070 in. screen basket	Feed	1.2	664	47.1	15.4	2.0	60
	Rejects	2.5	724	58.8	7.6		
	Accepts	0.5	249	20.9	34.9		
0.085 in. screen basket	Feed	1.2	661	48.0	14.1	1.6	64
	Rejects	1.9	706	54.2	13.0		
	Accepts	0.7	412	28.7	25.8		

R28 = combined Bauer McNett R14 and P14/R28 fractions; T_R = thickening ratio; RRw = mass reject rate.

I. Pulp properties of the screen feed, accepts, and rejects.

using the 0.060 in. basket. Those results also show that the ISSF using the 0.060 in. basket resulted in over 500 points of freeness drop at 68% reject rate, while freeness drop between the feed and accepts using the 0.085 in. basket was only about 250 mL.

Specific energy consumption

Table II describes the legends used in the remaining figures.

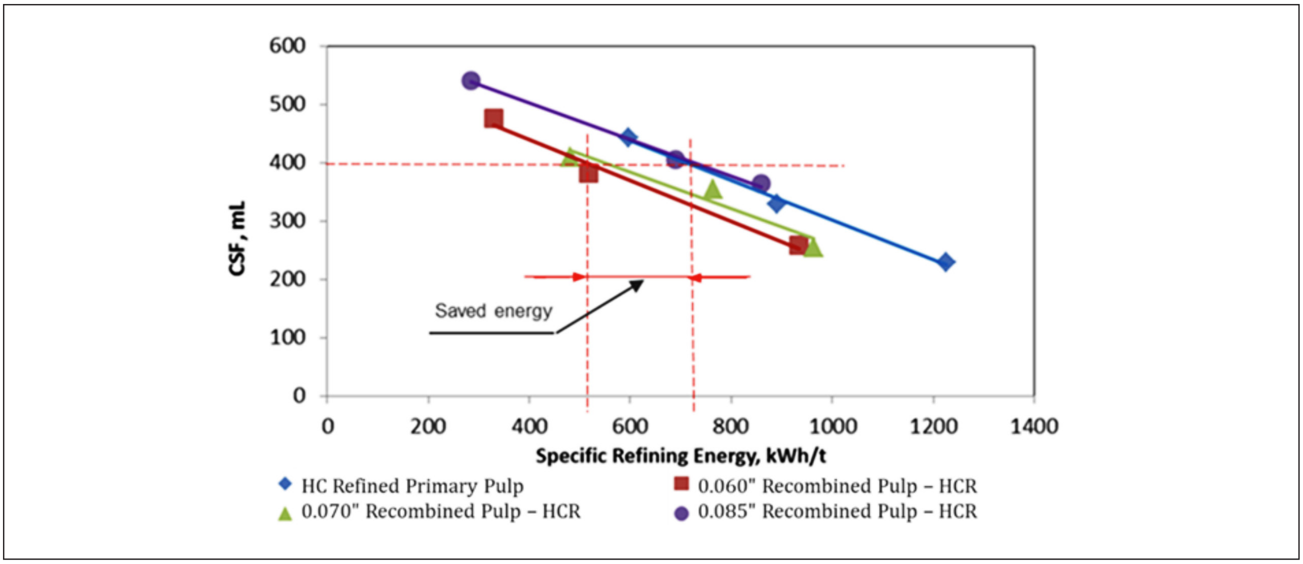
Figure 6 shows freeness vs. specific refining energy consumption for the different configurations studied: HC refined primary pulp (control sample, no ISSF) and recombined pulp (refined rejects + accepts) with different screen hole size baskets. The results show that compared to the control sample, the recombined pulps (ISSF with 0.060 in. or 0.070 in. hole diameter) required less refining energy to reach the same freeness. The ISSF with the 0.085 in. screen basket did not lead to any reduction in overall refining energy. This finding shed light on the importance of basket size selection for application of the ISSF for production of CTMP pulp.

An illustration of the saved energy at 400 mL freeness level with ISSF is shown in Fig. 6. In order to reach 400 mL freeness for the recombined pulp, two different options could be envisaged. One was to fractionate the accepts stream to 400 mL freeness and target the same freeness for refined rejects (ISSF using 0.085 in. screen basket in this study). The other option was to fractionate the primary pulp into accepts with freeness levels below 400 mL and refined rejects to freeness levels greater than 400 mL (ISSF

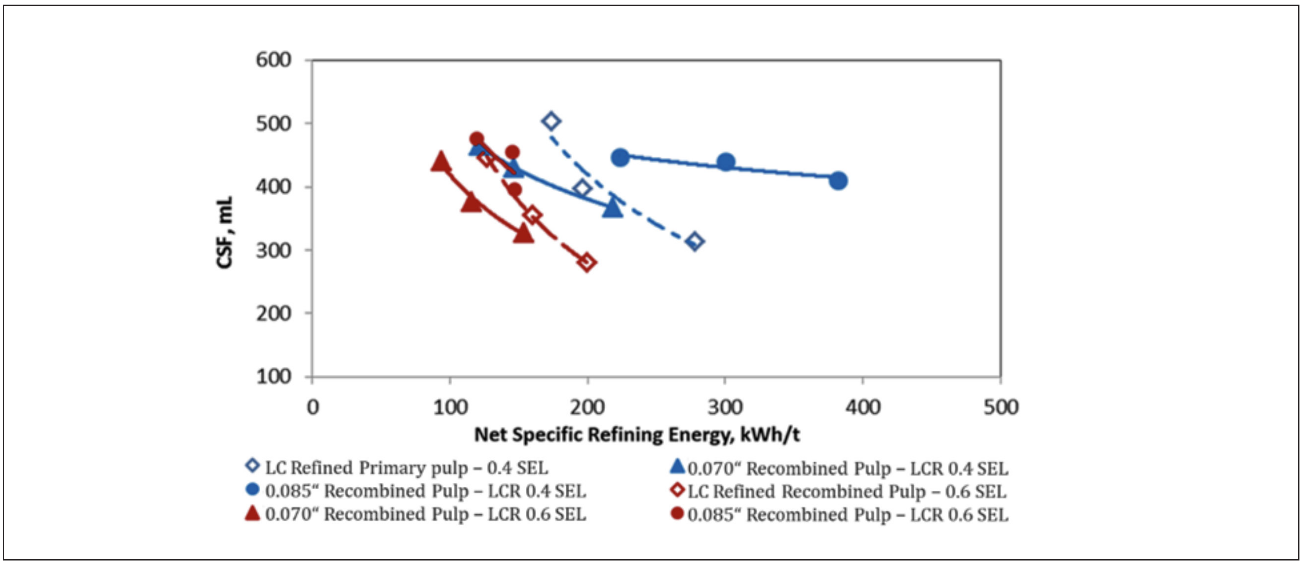
Symbol	Legend	Description
	Primary pulp	First stage HC refined pulp collected at a western BCTMP mill
♦	HC refined primary pulp	Collected primary pulp refined at FPI pilot plant using HCR as secondary stage
▲	LC refined primary pulp – 0.4 SEL	Collected primary pulp refined at FPI pilot plant using LCR at 0.4 J/m SEL as secondary stage
●	LC refined primary pulp – 0.6 SEL	Collected primary pulp refined at FPI pilot plant using LCR at 0.6 J/m SEL as secondary stage
	Recombined pulp	Accepts + refined rejects (ISSF rejects from 0.060 in., 0.070 in., or 0.085 in. screen baskets)
◊	Recombined pulp – HCR	Accepts + rejects of ISSF with 0.070 in. basket and refined by HCR as secondary stage
△	Recombined pulp – LCR 0.4 SEL	Accepts + rejects of ISSF with 0.070 in. basket and refined by LCR at 0.4 J/m SEL
○	Recombined pulp – LCR 0.6 SEL	Accepts + rejects of ISSF with 0.070 in. basket and refined by LCR at 0.6 J/m SEL

BCTMP = bleached chemithermomechanical pulp; HCR = high consistency refining; LCR = low consistency refining; FPI = FPInnovations; SEL = specific edge load; ISSF = interstage screening fractionation.

II. Description of legends used in the figures.



6. CSF vs. specific refining energy – HCR.



7. CSF vs. net specific refining energy – LCR.

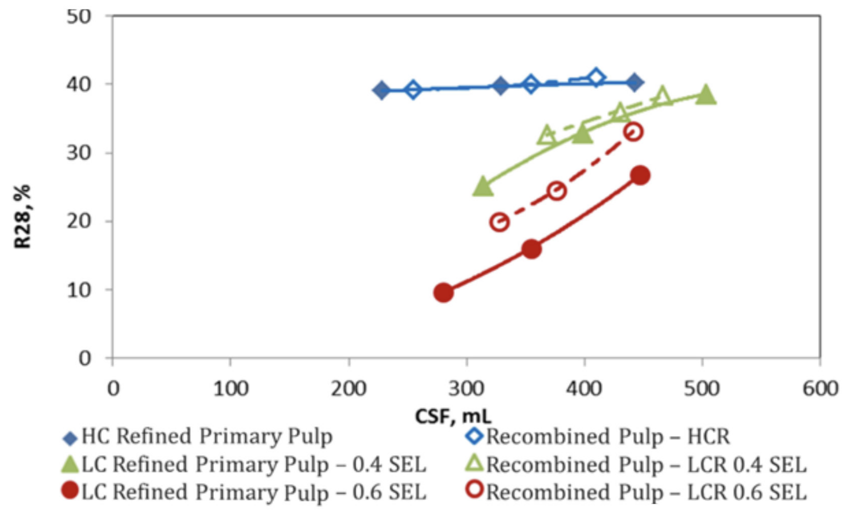
using 0.060 in. and 0.070 in. screen baskets). Compared to option 1, the rejects stream from the second scenario did not need to be refined to 400 mL CSF, and therefore, less refining energy was required to refine the rejects and produce a recombined pulp at 400 mL CSF.

Figure 7 shows a comparison of net refining energy consumption between LC refined primary pulp (no ISSF) and recombined pulp at two different refining intensities. Due to some screening system plugging issues while using the 0.060 in. screen basket, only ISSF with 0.070 in. and 0.085 in. screen baskets are shown. As in the case of HCR (Fig. 6), a savings in refining energy was achieved after ISSF using 0.070 in. screen baskets followed by LC refining of rejects. No savings in energy was obtained with ISSF using the 0.085 in. screen basket. When refined to a given freeness level, increasing refining intensity (SEL) from 0.4 J/m to 0.6 J/m led to further reduction in refining specific energy with or without ISSF.

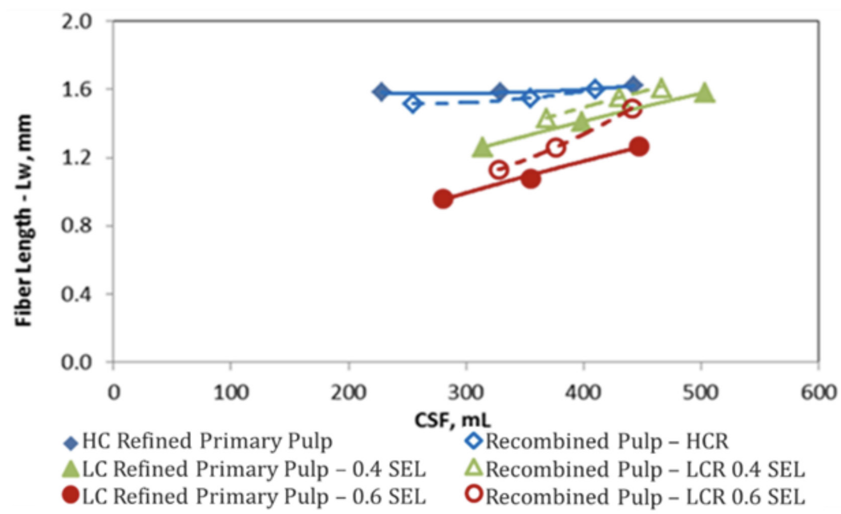
As ISSF with the 0.085 in. screen basket did not offer any advantages for saving refining energy, primary pulp processed in ISSF with the 0.070 in. screen fractionation was chosen as the optimum pulp processing condition. Measurement and analysis of all pulp and handsheet properties were carried out on pulps produced under the previously mentioned condition and are described in the following sections.

Pulp and handsheet properties

As can be seen in **Fig. 8**, after HCR to a given freeness level, refined primary and recombined pulps had similar long fiber fraction content (R28), indicating that ISSF with the 0.070 in. screen basket did not have any negative im-



8. R28 vs. CSF.



9. Fiber quality analyzer (FQA) fiber length vs. CSF.

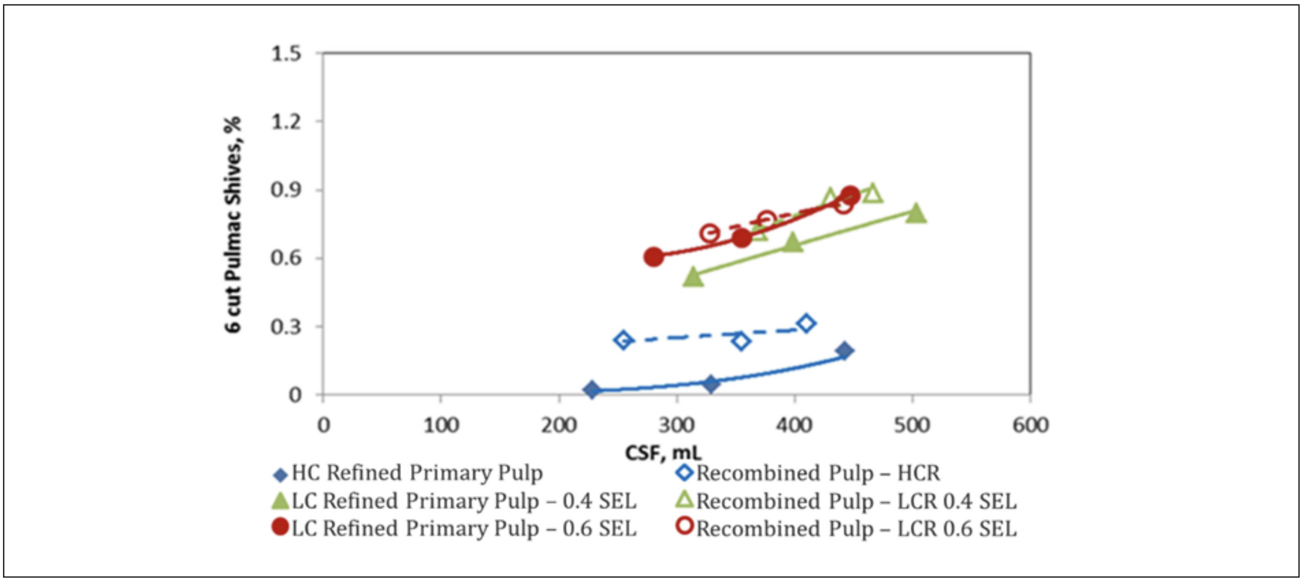
pact on long fiber content of the recombined pulps. Therefore, savings in energy with ISSF followed by HCR of rejects is not at the expense of fiber length or long fibers content. This is also shown in the result of FQA fiber length analysis (**Fig. 9**).

Compared to primary pulp, when refined in LCR to the same freeness level, recombined pulp had a similar R28 long fiber fraction content at lower SEL of 0.4 J/m and a higher R28 long fiber fraction content at higher SEL of 0.6 J/m (Fig. 8). This would indicate that fiber length was better preserved when rejects of the ISSF with the 0.070 in. basket is LC refined as opposed to LCR of the primary pulp. The ISSF with the 0.070 in. basket followed by LCR of rejects showed less sensitivity to refining intensity than mainline LC refining (LCR without ISSF) of primary refined pulp. In LCR, the separated longer and coarser fibers in the reject stream could withstand a higher refining intensity than fibers in unscreened primary refined pulp.

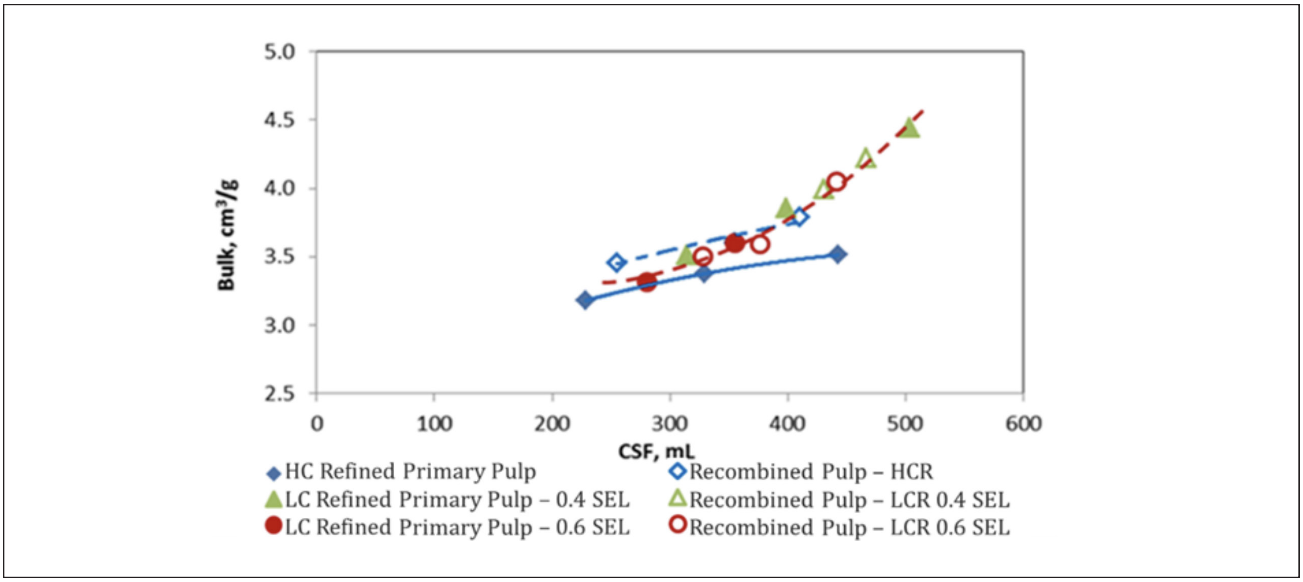
The results in Figs. 8–9 also demonstrate the sensitivity of the mainline LCR to refining intensity. Under the same SEL levels, mainline LCR at 0.4 J/m showed substantially higher R28 content and longer fiber length as compared to those at 0.6 J/m SEL. This observation is in agreement with previous works in LCR of mechanical pulp [16,17].

Compared to HCR, LCR tends to shorten fibers, particularly at higher SEL values. The LC refined pulps with and without ISSF had lower R28 content and lower average fiber length compared to those of the HC refined pulps (Figs. 8–9).

Figure 10 indicates that at a given freeness and com-



10. The 6 cut Pulmac shives vs. CSF.



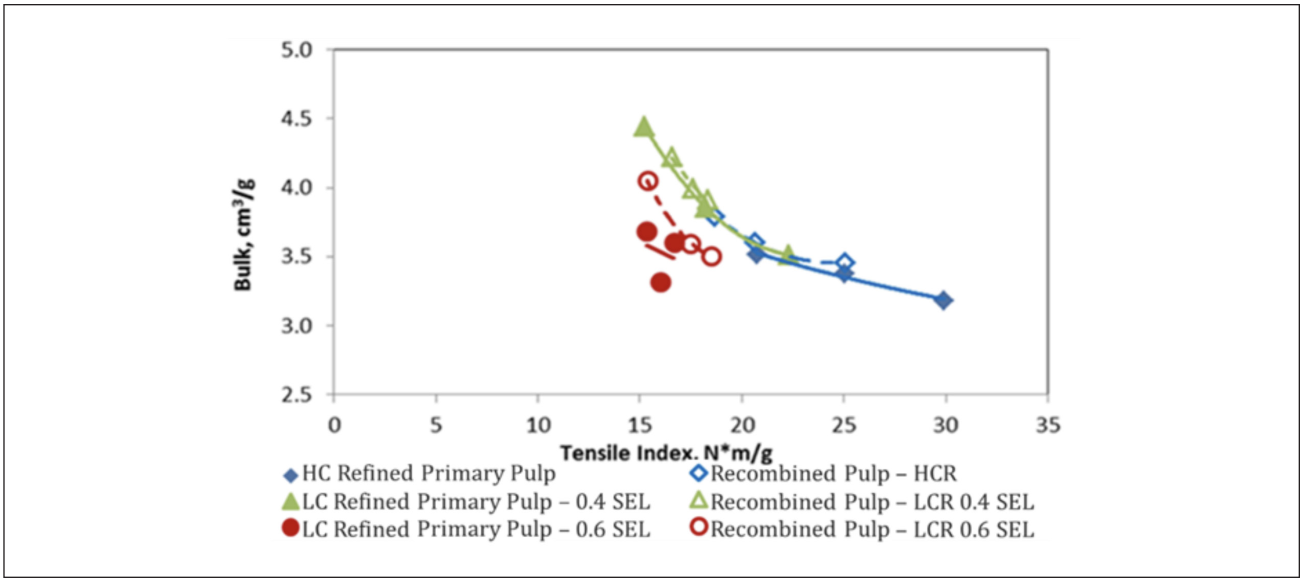
11. Bulk vs. CSF.

pared to primary pulp, recombined pulps had similar or slightly higher shives content. As discussed previously, compared to the primary pulp, less refining energy was consumed by the recombined pulp with ISSF using a 0.070 in. screen basket. The accepts stream for the ISSF trial with the 0.070 in. screen basket contained about 0.8% shives content. Optimizing the screening and cleaning system might be needed when ISSF is implemented in a BCTMP production process.

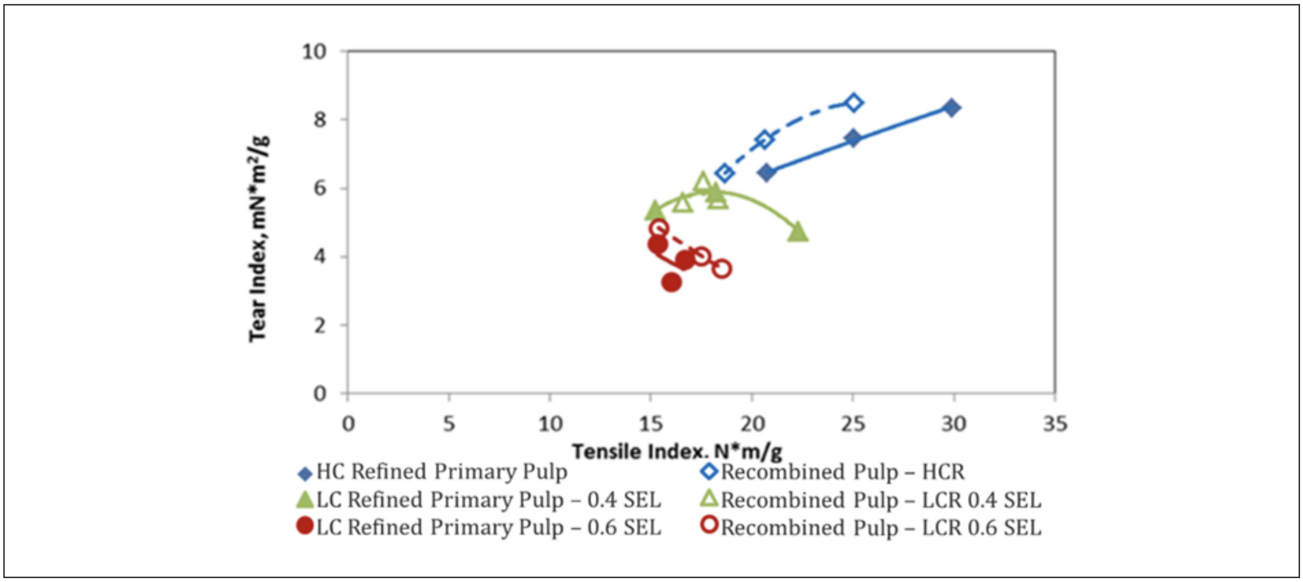
Bulk is the most important property of BCTMP pulp produced for board grade applications. High bulk pulp furnish also offers an opportunity for paper producers to reduce fiber consumption in their papermaking process and offers a possibility of using those fibers for specialty grades where high bulk and/or high absorbency are required. Compared to primary pulp refined to the same freeness level, recombined pulp always had a higher bulk when HCR was used (**Fig. 11**). In LCR, bulk was maintained with and without ISSF. Compared to mainline refining, ISSF did not have any negative impact on bulk development.

Generally, bulk is influenced by fiber morphology, fiber length distribution (long, short, and fines fractions), and fiber wall collapse during refining. The LC refined primary pulp and recombined pulp had shorter fiber length and lower long fiber fraction content when refining was done at higher SEL (Figs. 8–9). It is therefore critical to choose a proper SEL for producing high-bulk grade BCTMP when LCR is implemented.

Figure 12 indicates that both primary and recombined pulps with HCR and LCR at 0.4 SEL had similar bulk vs.



12. Bulk vs. tensile index.



13. Tear index vs. tensile index.

tensile strength development curves. Compared to HC refining, LCR at 0.4 J/m with and without ISSF showed a similar behavior in this relationship. The results confirmed that LCR at low SEL could produce BCTMP pulp with similar bulk–tensile strength properties as those in HCR, but with lower refining energy consumption. The LCR at 0.6 J/m SEL with and without ISSF further reduced refining energy consumption but had a lower bulk–tensile strength relationship compared to LCR at 0.4 SEL. At a given tensile index, ISSF followed by LCR of rejects at 0.6 J/m showed an improved bulk as compared to mainline LCR at the same SEL. The ISSF followed by LCR of rejects at low SEL is therefore recommended for development of bulk–tensile strength properties.

Figure 13 shows the tear index as a function of tensile index for HC and LC refined primary and recombined pulps. In general, under HCR, tear strength increases with the development of tensile strength until there is significant decrease in fiber length. The same trend was shown with LCR at 0.4 J/m SEL; tear strength first increased with the development of tensile strength and then decreased with the further development of tensile strength. In LCR at a higher SEL of 0.6 J/m, tear strength continuously decreased with the development of tensile strength. This is attributed to fiber shortening occurring during the refining at higher SEL. For a given tensile strength, and compared to the primary pulp, recombined pulps using ISSF followed by HC rejects refining had the highest tear index.

Comparison at 400 mL CSF	HCR		LCR			
			SEL = 0.4 J/m		SEL = 0.6 J/m	
	Without ISSF	With ISSF	Without ISSF	With ISSF	Without ISSF	With ISSF
Net refining energy, kWh/metric ton*	708	533 (-25%)	232	172 (-26%)	144	107 (-26%)
Fiber length (Lw), mm	1.60	1.59	1.41	1.50	1.17	1.34
6 cut Pulmac shives, %	0.14	0.30	0.67	0.80	0.78	0.80
Bulk, cm^3/g	3.46	3.76 (+0.3)	3.87	3.95 (+0.08)	3.65	3.77 (+0.12)
Tensile index, N·m/g	22.4	19.0	18.1	17.9	16.0	16.7
Tear index, mN·m²/g	6.82	6.63	5.88	5.96	4.15	4.33

* Net refining energy does not include the energy consumed to produce the primary pulp at the mill.
HCR = high consistency refining; LCR = low consistency refining; SEL = specific edge load; ISSF = interstage screening fractionation.

III. Refining energy consumption and pulp and handsheet properties with and without ISSF.

Impact of ISSF on refining energy savings and pulp quality

The impacts of ISSF combined with rejects refining on energy savings and final properties are summarized in **Table III**.

As shown in Table III, compared to mainline refining, ISSF followed by refining of screen rejects resulted in reduced refining energy consumption and increased sheet bulk, with no significant changes to other pulp and handsheet properties.

1. ISSF + HCR vs. HCR
   Compared to HCR at a target freeness level of 400 mL, about 25% refining energy could be saved if ISSF is implemented. Increased bulk and no adverse effect on fiber length were observed. There was a slight decrease in tensile and tear strength and a slight increase in shives content.
2. ISSF + LCR vs. LCR
   About 26% savings in energy consumption could be achieved if ISSF followed by rejects refining at low SEL is implemented. In this case, similar bulk and tensile and tear strength were obtained. Shives content was slightly higher.
   Also, increasing refining intensity from 0.4 J/m to 0.6 J/m led to higher fiber shortening during refining. It consequently produced pulps with lower bulk and lower tensile/tear strength properties.

CONCLUSIONS

Implementation of ISSF combined with rejects refining could lead to savings in refining energy consumption when compared with traditional two-stage high consistency refining of BCTMP. The key process parameters are the screening process operating conditions, e.g., mass reject rate and proper screen basket hole size. In our study, an ISSF using a 0.070 in. round hole screen basket with smooth profile and a mass reject rate of 60%–70% provided the best condition for reducing energy consumption with no negative impact on bulk–tensile properties when compared to the traditional two-stage HC refining to produce BCTMP.

Compared to the control pulp (two-stage mainline high consistency refining) and when refined to the same freeness level of 400 mL, ISSF followed by HCR of rejects resulted in about 25% savings in refining energy consumption. The produced pulp had higher bulk and similar fiber length, but slightly lower tear and tensile strengths compared to those of the control pulp. When ISSF was followed by LCR of rejects and refined to the target freeness of 400 mL, the net LCR energy savings compared to the control (one stage mainline HCR + one stage mainline LCR) was about 26%. The produced pulp had similar bulk and strength properties as those of the LCR control pulps. Increasing refining intensity in LCR led to a higher reduction in refining energy consumption. However, the increase in SEL also led to more fiber shortening and lower bulk and strength properties. **TJ**

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About this journal

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Mechanical BCTMP production requires high energy consumption, which accounts for a major portion of the production cost. To stay competitive, mills need to reduce energy costs. The research here is one of the technologies we developed and studied to achieve energy savings for BCTMP production.

Budget management was the most difficult aspect of this research. We shared and used budgets/resources from two different research programs to successfully complete the study. The research involved lots of reading, data collecting, analyzing, and understanding of the research process. It is evident that a workable budget and timeline for conducting research is needed.

The study demonstrated that mainline interstage screen fractionation and low consistency rejects refining strategy can reduce refining energy consumption with maintained or increased pulp properties. The findings here offer pulp mills great potential to produce low-carbon, low-energy TMP and BCTMP products. Our next step is to collaborate with industry for the potential implementation of the technology.

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