Two-stage low-consistency refining of mechanical pulp

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SUMMARY

The objective of this study was to reduce energy demand in the mechanical pulp refining process by substituting second stage high consistency (HC) refining with two stages of optimised low consistency (LC) refining. Primary refining of Spruce-Pine-Fir wood chip mix was carried out using the Advanced Thermo-Mechanical Pulp (ATMP) refining process employing mechanical chip pre-treatment in the RT Pressafiner and Fiberizer prior to high-intensity refining with the addition of 3.1% bisulphite. A portion of the primary pulp was subjected to a second stage HC refining, and the other part subjected to two stages of LC refining. The results indicate that the two stages of optimised secondary LC refining reduced the gross refining energy by approximately 300 kWh/odt compared to second stage HC refining. The target tensile index of 40 Nm/g required approximately 1450 kWh/odt of gross HC refining energy, and only 1150 kWh/odt using primary HC followed by secondary LC refining. Compared to HC-refined pulps, at a tensile index of 40 Nm/g, the LC-refined pulps had a similar freeness, light scattering coefficient and density, but lower TEA, stretch, tear index and average fibre length. The different pulp properties are believed to originate from the different fibre length distributions resulting from these two refining methods.

KEYWORDS:
Mechanical Pulping, Pulp Quality, LC refining, Energy Reduction, ATMP

INTRODUCTION

Reduction in the electrical energy demand in mechanical pulping has become more acute with a constantly increasing electricity cost. New process solutions have been developed to address these needs; one of them is ATMP process which was commercially introduced in 2010 (1). The ATMP process consists of unit operations formulated to separately defibrate wood chips before subsequent fibrillation of the wood fibres to improve fibre bonding. Substantial refining energy reduction (more than 40% or 1 MWh/odt) has been reported using the ATMP process when compared with pulps of similar quality from a conventional thermo-mechanical pulping process (2-4). Another way of reducing the electrical energy demand is by utilising LC refining after the first stage HC refining. Replacing a second stage HC refiner with LC refining has been reported to reduce the total energy demand to reach a tensile index of 40 Nm/g by 300 kWh/odt for Norway spruce (5, 6). Pilot scale ATMP studies demonstrated a 100-200 kWh/odt reduction in the total refining energy, when compared at a similar tensile index of 40 Nm/g, by replacing the second stage HC refiner with multiple stages of LC refining; total refining energy was less than 1000 kWh/odt (7-8). At the same tensile index, the LC-refined pulps had a similar freeness and light scattering coefficient, however both tear and average fibre length were lower compared to the HC-refined pulps. Another study on Norway spruce reported approximately 15% reduction in refining energy at equal tensile index where the second stage HC refining was substituted with LC refining (9). As in prior studies, the LC-refined pulps had a reduced fibre length compared to the HC-refined pulps. Recent studies with industrial scale second stage LC refining showed that it is possible to reduce the gross energy demand by approximately 100 kWh/odt utilising LC concept although the LC-refined pulps showed no development in the light scattering coefficient (10, 11). This study compared first stage ATMP pulps that were treated by secondary HC and secondary LC refining. The target was to achieve a tensile index of 40 Nm/g (common target of newsprint mills), and compare other pulp properties of the HC- and LC-refined pulps at this tensile index. Pulp properties evaluated included freeness, light scattering coefficient, density, tear index, tensile energy absorption, stretch and length weighted average fibre length.
MATERIALS AND METHODS

The mixed softwood chips were supplied from the interior of British Columbia, Canada and consisted of approximately 80% Lodgepole pine, and the remainder of Sitka spruce and some Western balsam fir. The ATMP process described in the literature (1-4) was used for this study. Figure 1. The chips were pre-heated and defibrated using RT Pressafiner and Fiberizer stages. The fibrous material was then high intensity HC refined with addition of 3.1% bisulphite added directly into the refiner. The bisulphite decreased the pH from 5.5-6 (common level for TMP) to 4.7. The chip pre-treatment, and primary HC refining were conducted at the Andritz pilot plant in Springfield, OH, USA. The specific energy inputs (SEC) in the primary pulp totalled 800 kWh/odt: 40 kWh/odt in the RT Pressafiner, 230 kWh/odt in the Fiberizer and 530 kWh/odt in the first stage HC refiner. The freeness was 487 CSF and the tensile index was 21.6 Nm/g. A portion of the first stage pulp was second stage HC refined at the Springfield pilot plant using an atmospheric double-disc Andritz 401 refiner at four different energy inputs: 610, 770, 870, and 1000 kWh/odt. The target tensile index of 40 Nm/g was achieved with 1450 kWh/odt. The pulp freeness was approximately 140 CSF. The remainder of the pulp was shipped to the Pulp and Paper Centre at the University of British Columbia, in Vancouver, Canada, for two stage secondary LC refining which was performed using a 14” Aikawa LC pilot single disk refiner equipped with 16” overhung segments and driven by a 110 kW variable frequency motor. The AFT Aikawa Fibre Technologies FineBar segments used had a BEL (Bar Edge Length) of 5.59 km, groove depth of 4.8 mm, groove width of 2.4 mm, bar width of 1 mm, and bar angle of 15°. Figure 1 shows an illustration of the refining configuration. The pulp volumetric flow rate was maintained for all series at approximately 200 litres per minute. Changes in motor load were obtained by changing refiner plate gap. Changes in the gap were accomplished by shifting the rotor position while the stator remained stationary, fixed to the refiner housing. Measurements for the gap size were obtained using a LVDT sensor connected to the rotor shaft. Prior to each refining series the LVDT sensor was calibrated by bringing the plates to a touch without turning the refiner on. Two trials were conducted to optimise the refining conditions for the two consecutive LC refining stages. The objective of the first series was to optimise the first stage LC conditions by generating an energy curve where different motor loads (gaps) were applied to the same feed pulp. The motor load which gave the greatest pulp quality development was selected as optimum. The second series aimed at optimising the second LC refining stage. Taking a batch of pulp from the first LC stage with the optimum first stage conditions, different motor loads were used to obtain another energy curve. Prior to each trial the pulp was disintegrated for 4 hours at 60 °C. Refining consistency in the first series was 3.4% and the second series 3.0%. The difference in consistency was unintentional (a result of uneven dilution). The gross SEC in the first LC trial was varied from 70 to 180 kWh/odt, and in the second trial from 70 to 240 kWh/odt. The reported LC refiner energy inputs were calculated based on the gross refiner motor loads; hence the measured no-load of 25 kW has not been deducted. It should be noted that the proportional no-load power decreases with increasing LC refiner diameter. For the 16” pilot refiner used in the trial, the average no-load specific energy was 55 kWh/odt for the first series, and 72 kWh/odt for the second series. The typical no-load specific energy of a 58” industrial refiner is 25-30 kWh/odt. Laboratory testing of pulp and sheets was conducted according to TAPPI standards at the UBC Pulp and Paper Centre laboratory. Optical fibre characterisation was performed using FQA (Fibre Quality Analyzer). Freeness measurements were carried out at the Andritz Springfield pilot plant. The standard deviation of the results were calculated where possible and plotted as error bars.

RESULTS AND DISCUSSION

Figure 2 shows the relationships between the LC refiner plate gap and the net motor power. The net power increased with decreasing gap. The decreasing gap size causes an increase in friction between the refiner segments and pulp suspension, therefore increasing the motor power. The relationship appears to be linear up to the point where the plate gap became small enough (<0.05 mm) for the fibre pad to collapse. There appears to be a small but constant difference in gap sizes at equal motor power between the first and second refining trials. The difference can be attributed to a combination of both different feed pulp properties and the slightly lower pulp consistency in the second trial. Since both trials had a similar flow rate, the
lower consistency pulp would have generated a pad with less fibre in the second refining series.

Refining intensities (expressed as Specific Edge Load, SEL), gross SEC and gap sizes for both LC refining trials can be found in Table 1. A SEL of 0.38 J/m gave the greatest property development in the first trial, while a SEL of 0.24 J/m gave the greatest property development in the second trial. In such a study where both the refiner plate design and rotational speed are kept constant, the SEL intensity is a linear function of the net motor power. The results indicate that the optimum LC refining intensity varies for different feed pulps. Optimum SEL intensity decreased with decreasing feed pulp freeness, similar to results found in the literature (8, 12).

In the first stage the tensile index development reached a maximum increase at a gap size in pulp quality development in LC refining has been previously shown (13, 14). The gross specific energy required to increase the tensile index by 1 Nm/g was approximately 18 kWh/odt in the first LC stage and 11 kWh/odt in the second stage; the SEL was 0.38 and 0.24 J/m respectively. Different values can be interpolated from the literature. Both pilot and mill data show a similar 17 kWh/odt per unit of tensile using SEL’s of 0.5 and 0.6 J/m respectively (6, 7). Other data reveals values of 20 kWh/odt per unit of tensile at 0.31 J/m and 43 kWh/odt per unit of tensile at 0.41 J/m, (8). The lack of a universal correlation between the SEL intensity and tensile development shows that the SEL theory does not fully characterise the LC refining action. Similar conclusions have been previously reported (14).

The measured no-load power for the pilot refiner averaged approximately 25 kW, resulting in approximately 55 kWh/odt in the first stage and 72 kWh/odt in the second stage due to the different consistencies in the two trials. The cumulative specific energy for the two LC stages was approximately 310 kWh/odt gross, or 180 kWh/odt net.

The differences in tensile strength development energy efficiency between this study and the values reported in the literature depend on the different refining conditions and feed pulp, both influenced by species mix and refining degree before the LC refining. The two parameter characterisations with SEC and SEL alone have been shown to insufficiently characterise the refining action, whereas a three parameter characterisation has been claimed to account for 90% of the variability in the data (15). The missing third parameter is claimed to be related to the forces on fibres (16). A characterisation of the refining action using only machine parameters like SEC and SEL takes neither the type of feed pulp nor the fibre-refiner plate geometry interaction into consideration.

**COMPARISON OF PULP PROPERTY DEVELOPMENT IN LC AND HC REFINING**

Two stages of optimised LC refining after primary HC refining in the ATMP process decreased the overall energy demand by 300 kWh/odt (20%) compared to the HC refining at a tensile

![Fig. 3 Tensile index of handsheets produced from pulp refined in one and two LC stages](image)

![Fig. 2 Net refiner motor power at different LC refiner gaps in both refining stages](image)

![Table 1 SEL, SEC (gross) and gap in LC trials](image)

**OPTIMISATION OF LC REFINING**

Six different gap settings were used in the first series to determine the point of maximum tensile index development. In the second series, 5 different gap settings were used. Figure 3 shows the development of paper tensile index in the first and second refining stages. Some first stage trial points were repeated in the second trial. The repeatability of the results appeared to be satisfactory.

In the first stage the tensile index development reached a maximum increase at a gross specific energy of 143 kWh/odt for that stage. The tensile increased from 22 to 30 Nm/g, at a freeness of 205 CSF the maximum tensile index increase was achieved with a gross specific energy of 127 kWh/odt at a freeness of 132 CSF. The optimum gap size for maximum tensile index development was 0.33 mm in the first stage and 0.39 mm
index of 40 Nm/g. Figure 4 shows that the cumulative specific energy input to produce the 40 Nm/g tensile pulp with LC refining was little over 1150 kWh/odt, whereas HC refining required 1450 kWh/ton.

In general, there is good correlation between the increase in tensile and decrease in freeness for both the LC and HC data (Fig. 5).

![Fig. 4](image1.png) Tensile index of handsheets produced from LC and HC refined pulp.

![Fig. 7](image2.png) Relationship between apparent density of paper and tensile index.

![Fig. 5](image3.png) Relationship between tensile index and freeness.

![Fig. 8](image4.png) Relationship between tensile energy absorption and tensile index of handsheets.

![Fig. 6](image5.png) Relationship between light scattering coefficient and tensile index of handsheets.

![Fig. 9](image6.png) Relationship between tear index and tensile index of handsheets.
Figures 6 to 10 illustrate the development of light scattering coefficient, density, tensile energy absorption (TEA), tear index and average fibre length as a function of the tensile index development of handsheets. The intention was to compare these properties at the target tensile index of 40 Nm/g for both the HC and LC pulps.

Both the light scattering coefficient and apparent sheet density indicated similar development in both LC and HC refining (Figs. 6 and 7). This contradicts previous results where no light scattering development was reported for LC-refined pulps (11). The TEA, tear index, and length weighted average fibre length all show lesser values for the LC refined pulp compared at equivalent tensile with the HC refined pulps (Figs. 8-10). Fibre length reduction is a known characteristic of LC refining. The shorter fibre length results in a decreased tear index. The reason for the lower TEA with LC refining remains unknown and is subject for further study.

![Fig. 10](image)

**Fig. 10** Relationship between average fibre length (l.w.) and tensile index of handsheets.

It should be noted that the comparisons between LC and HC refined pulp quality development in this study were made for the ATMP process, whereas the quality development with a conventional TMP process is quite different. A comparison between these three processes is presented in Table 2. The TMP values are interpolated from Andritz pilot plant data on the same species mix and machinery as used for the ATMP-HCR data. While paper machines with large draws are more likely to suffer from lower TEA, many mills with modern machines where draws are minimised may not be negatively affected by this phenomena. It should also be considered that laboratory sheets are much more anisotropic compared to machine produced paper, where fibres are oriented in the machine direction, and this might have an impact on the difference in TEA sensitivity. Realistic implications of these findings on such variables as dewatering and runnability can only be studied on a full-size paper machine. A referenced mill installation had no negative implications on paper machine runnability after installing LC refining (11). It should also be noted that the pulp properties in Table 2 are from handsheets made exclusively of the experimental pulp, whereas it is recognised that multiple pulps and additives are combined in actual paper machine operations. The pulps produced from the HC and LC processes demonstrated similar drainage and tensile strength properties; however the LC pulps had a lower average fibre length. This suggests a fundamental difference in fibre development between these two processes. It is of interest to study not only the average fibre length but the distribution of the fibre sizes for both LC and HC refining. The first stage feed pulp and the HC/LC pulps samples with an approximate tensile index of 40 Nm/g were fractionated using the Bauer-McNett Classifier. The fraction ratios are presented in Figure 11. Compared to the feed pulp, both HC and LC pulps show minor changes in the R14 and R200-fractions, and a notable increase in the P200-fraction. The differences remain in the three middle fractions. The amount of the R28-fraction in HC pulp decreased; however the R48 and R100-fractions were similar to the feed pulp. The LC pulp showed a major decrease in the R28-fraction, and significant increases in the R48 and R100-fractions. Neglecting the P200-fraction, the LC pulp fractions form a bell-curve distribution, which indicates a greater homogeneity in the fibre suspension. Similar differences in the fibre size distributions are reported in the literature (6, 18). The more uniform LC pulp fibre size distribution may better bear the tensile load, as there are less possible stress concentrations for crack propagation.

**Table 2** Process comparison at equal tensile index

<table>
<thead>
<tr>
<th>Pulp Property</th>
<th>ATMP/LC</th>
<th>ATMP/HC</th>
<th>TMP/HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile [Nm/g]</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>SEC [kWh/odt]</td>
<td>1150</td>
<td>1450</td>
<td>1900</td>
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<tr>
<td>Freeness [CSF]</td>
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<td>130</td>
<td>120</td>
</tr>
<tr>
<td>Density [kg/m³]</td>
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<td>390</td>
<td>390</td>
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<tr>
<td>Stretch [%]</td>
<td>1.9</td>
<td>2.3</td>
<td>1.9</td>
</tr>
<tr>
<td>TEA [J/m²]</td>
<td>31</td>
<td>44</td>
<td>29</td>
</tr>
<tr>
<td>Tear [mNm²/g]</td>
<td>5.5</td>
<td>7.2</td>
<td>8.8</td>
</tr>
<tr>
<td>Fibre length [mm]</td>
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<td>1.55</td>
<td>1.35</td>
</tr>
<tr>
<td>Scattering [m²/kg]</td>
<td>59</td>
<td>59</td>
<td>57</td>
</tr>
</tbody>
</table>

**Fig. 11** Fractional composition of the pulps

**FUTURE WORK**

A detailed analysis of fibre morphology would help to better understand the fundamental difference between HC and LC refining. A better understanding of the optimum fibre morphology would allow development of methods to further reduce the energy demand in mechanical pulping.
CONCLUSIONS

- Mechanical pulp with a tensile index of 40 Nm/g, light scattering of 59 m²/kg, and freeness of 140 CSF was produced using primary HC and secondary LC refining of primary refined ATMP.
- The HC refining required a total of approximately 1450 kWh/ton, whereas HC refining followed by the two optimised LC refining stages required a total of 1150 kWh/odt, approximately 300 kWh/odt less.
- Light scattering coefficient and apparent density of the sheets developed similarly for both HC and LC refining.
- The tear index, length weighted average fibre length, stretch and TEA were lower for the LC-refined pulp.
- Differences in the fibre size distributions indicate that LC refining produced a more homogeneous distribution compared to HC refining.

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