Optimal Refining Strategy of High Yield Unbleached Long Fibre Kraft Pulp: In-situ Investigation

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Abstract

Optimization of pulp refining is recognised as a critical step in the paper making process. Final product quality can be greatly influenced by the treatment of the fibres during refining. Incorrect refining of stock can lead to either insufficient fibrillation or excessive fibre damage. Optimization of refining intensity can lead to save power consumption and optimize the fibre quality. Refining results of low Kappa unbleached softwood kraft pulps are available in the literature based on investigation from laboratory PFI mills, pilot refiners and commercial refiners. Availability of such data for high yield unbleached softwood kraft pulps are rather limited. The refining response of such pulps is expected to be different from conventional low Kappa long fibre kraft pulps. The effect of refining intensity and mode of refining of such pulp while refined using two refiners in series was investigated using commercial paper machine refiners in a modern paper mill. Results of handsheet papers made from refined pulps from of in-situ trials showed that higher refining intensity in excess of 3.1 Ws/m is essential for better fibrillation and fibre development of such pulps. Close to 20% improvement in key strength properties (tensile, burst, STFI and ring crush compression strength) was achieved when refining intensity increased from 3.8 Ws/m to 5.6 Ws/m at constant net specific energy of 110 kWh/t. For two refiners operating in series, the optimal mode of operation was found to be use of higher intensity at the first refiner followed by lower intensity at the second refiner compared to use of same intensity in both refiners at the same total net specific energy applied.

Keywords

High yield, refining intensity, specific edge load, specific refining energy, optimization, Kappa Number, delignification, fibrillation, fibre length, fibre fines, distribution, freeness drop, micrograph, fibre morphology.

Introduction

While full chemical pulps of lower yields produce pulp with highest physical strength, such a high degree of delignification is not required for many paper grades. Higher yield pulps require more beating or refining to develop necessary strength. For certain grades, such as those used for packaging applications, increased refining energy and possible decrease in machine speed due to poor drainage are offset by the economics of higher yield. While conventional kraft cooking process normally produces yields in the range of 40% to 48%, mills producing linerboard often operate at levels of 58% to 60% yield. Before refining this high yield pulp to develop strength and bonding properties, the pulp needs to be separated into individual fibres or fiberized. This is generally accomplished by use of ‘pulp mill’ refiners such as blow line refiner, hot stock refiners and deshive refiners after the cooking stage. Operating conditions of these ‘pulp mill’ refiners are critical for efficient fiberization (1). The pulp mill refiners normally do not develop strength; it is the paper machine refiners that actually work on individual fibres for strength development.

A key step in the stock preparation phase is refining. For a given fibre, refining plays an important role in stock preparation as well as throughout the complete papermaking process (2, 3) in regard to product quality and on overall energy consumption figures. Next to raw material (fibre) selection, it has the greatest influence on final product quality. Specific refining energy must therefore always be held at an optimum without compromising on strength properties. This can be achieved by reducing hydraulic losses or no-load power and optimizing hydrodynamics in the actual refining process. For a given refiner, one way of saving energy is to control the refiner to maintain a constant specific edge load by varying speed according to production fluctuations. Another way of reducing energy consumption is to optimize the refiner fillings. This high ranking of refining in the papermaking process makes it all the more important to use correct refiner fillings and other optimum refining parameters. Application of incorrect refiner tackles can lead to the use of excessive power and the non-optimization of fibre development.

Voluminous amounts of data on refining response of low Kappa unbleached softwood kraft pulps are available in the literature based on investigation from laboratory PFI mills, pilot refiners and commercial refiners. However, limited refining data is available for high yield or high Kappa kraft pulps. The refining response of such pulps are expected to be different from conventional low Kappa unbleached long fibre kraft pulps (4, 5). Traditionally, studies to evaluate the impact of refining on pulp quality have been undertaken in the laboratory using the PFI mill (6, 7). This type of study provides little information in terms of defining the optimal refining parameters such as specific edge load, net specific energy, refiner fillings, and re-circulation, along with other operating variables of a practical nature (8, 9). Systematic refining investigation or trial using such pulps is necessary for establishing the optimal refining conditions (10). Execution of refiner trials at mills is often difficult without disrupting normal production. Moreover, it is very expensive to undertake such trial in terms of hardware requirements and machine time.

In some modern paper machines, the layout of the paper machine refiners, control arrangement and piping configuration can provide opportunity to undertake in-situ refining trial/investigation with minimal production disruption although quantification of fibre development in terms of finished product quality sometimes become very difficult. In this paper, results of fibre development at various ‘real-life’ refining conditions from such trials in a paper mill producing high quality kraft linerboard using high yield softwood chemical pulp at different refining intensity levels are presented. Results of different mode of refining of such pulp using two refiners operating in series are also included.

Mill Trial

The refining trial was undertaken while the paper machine was producing commercial products at normal throughput level. The stock preparation system of the machine has three double disc refiners. Two refiners are in series, feeding refined pulp to the bottom wire machine chest, while the third refiner supplies refined pulp to the top wire machine chest. The refined pulp from the two lines can be fed to either the bottom or top wire mixing chest via appropriate pipe and valve arrangement. This allowed the flexibility of changing throughput to bottom wire or top wire refiners as required during the trial without reducing the throughput of the paper machine. The layout the refiners are shown in Figure 1.

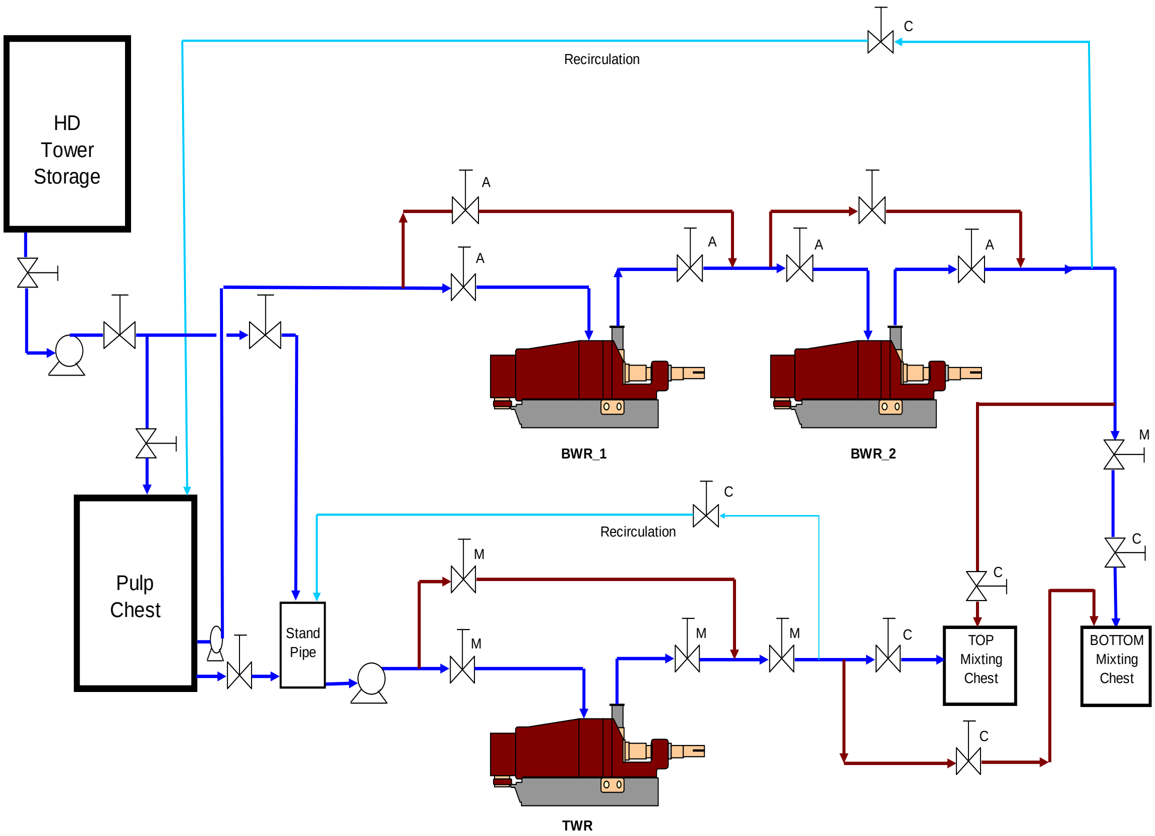

Figure 1 Layout of the refiners

Refiners

The top line had a single 48” double disc refiner, while the bottom line had two identical 42” double disc refiners operating in series. Virgin high yield softwood chemical pulp was refined in both the refining lines. Pulps from the same high density storage tower are drawn to feed the refiners at 4.5% consistency. For both the refining lines some level of re-circulation was maintained. The fillings of the bottom wire refiners were identical and had lower cutting edge length (km/rev) than that of the top wire refiner. The maximum total power available for each refiner was 1700 kW.

Trial Conditions

The flexible piping/control valve/flow meter arrangements of the stock approach system enabled undertaking the in-situ refining trial over a wider range of specific edge load (SEL) and net specific energy (NSE) without disrupting normal production. The details of trial undertaken are shown in Table 1.

Table 1 Trial Details

Line	SEL of first Refiner, Ws/m	NSE range, kWh/t	
TOP	1.5	64 – 75	
	2.0	62 – 94	
	3.1	99 137	
	2.5	84 115	
Bottom		First Refiner (R1)	Second Refiner (R2)
	2.0	45 -60	109 -123
	3.2	70 -97	75 – 99
	4.2	83 -128	45 – 85
	5.6	97 -142	43 – 70

The net power supply to the first (R1) of the two bottom wire refiners were kept constant to set a desired refining intensity for this refiner, while that of the second refiner (R2) was changed so that the total net specific energy applied on these two refiners remained constant at 170 kWh/t during the trial. At a constant net applied power (hence constant SEL), the NSE was changed by changing throughput through a particular refiner. Besides the above trials to investigate the effect of specific edge load at constant net specific energy for both the top and bottom line refiners, various modes of operation of the two bottom line refiners at NSE distribution to each refiner varying as (i) high/low to R1/R2; (ii) equal to both R1 and R2 and (iii) low/high to R1/R2 were also investigated.

Pulp Sampling

Pulp samples were collected from the following points/locations for evaluation (i) refiner outlet pipe (accept) and feed to the stand pipe for the top line refining trial; (ii) outlet of 1st bottom line refiner (mid-point; (iii) outlet of 2nd bottom line refiner (bottom line refiner accept) and (iv) after the pulp chest for bottom line refining trials.

Evaluation

Quantification of fibre development was carried out based of properties of fibres and hand sheet papers made from refined and unrefined pulps. The following properties were evaluated:
Handsheet: Tensile, TEA or Work-to-rupture and Stretch; Tear Strength, Burst, Ring Crush and STFI Compression Strengths, Porosity (Gurley Air Resistance), Gsm, caliper and density, Colour Parameters (L*, a* and b*);
Fibre: Fibre Length & Distribution, Fibre Fines, Fibre Coarseness, Morphology/micrographs, freeness

Results

In this work, two important refining parameters, SEL and NSE have been used to evaluate the refiner performances for fibre development. Detailed definitions of these parameters are shown in **Appendix**. For a given plate geometry, SEL can only be changed by changing refiner revolution per second (rps) and net power. Most commercial refiners are run at fixed speed. For such systems, any change in net power will also change the SEL value. Only option available for changing SEL of commercial refiner, without changing

NSE, is selection of correct plate pattern. In this trial the SEL was changed by changing the net power as the refiners were fitted with specific fillings mill was using at the time of the trial.

Effect of Refining Intensity

The optimum refining intensity for chemical pulps depends on the refining resistance, the physical dimensions, and the flocculation ability of fibres. For unbleached long fibre kraft pulp, the refining intensity can vary between 2.5 to 7.0 Ws/m. Optimum intensity values must be determined on a case by case basis by considering the properties of the fibre and the desired refining results. When refining long softwood fibres, too low intensity can not treat fibres effectively. On the other hand, too high intensity strongly shortens long softwood fibres and increases their dewatering resistance. This is particularly true for high-yield chemical softwood pulps. This is the main reason to undertake this trial to establish the optimal refining conditions.

<u>Fibre Properties</u>

Figure 1 shows the freeness changes of top line refined pulp as function of NSE at various specific edge loads for the top line refiner. The freeness drop varied between 0.4 and 0.8 per kWh/t over the SEL range investigated for this refiner. Similar results for the bottom line refiner are shown in Figure 2. The freeness drop over the first of the two bottom line refiners (mid point) varied between 0.9 and 1.4 per kWh/t, while the corresponding range of the two refiners combined (accept of bottom line refiners) was between 0.6 and 0.9. It us evident from these two figures that at higher specific edge load, freeness value at a constant net specific energy is lower.

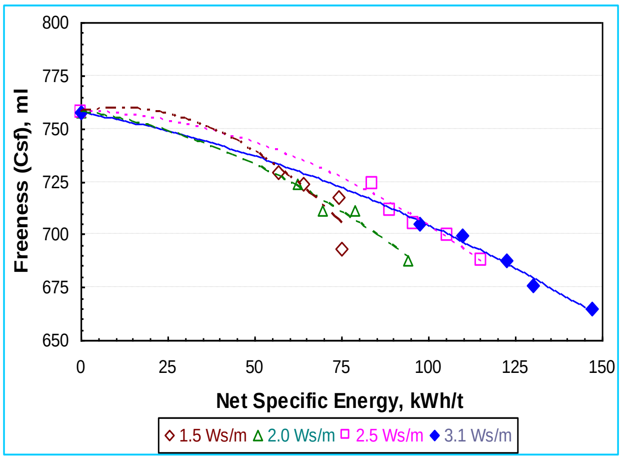

Fig. 1 NSE vs. Csf at various SEL (Top Refiner)

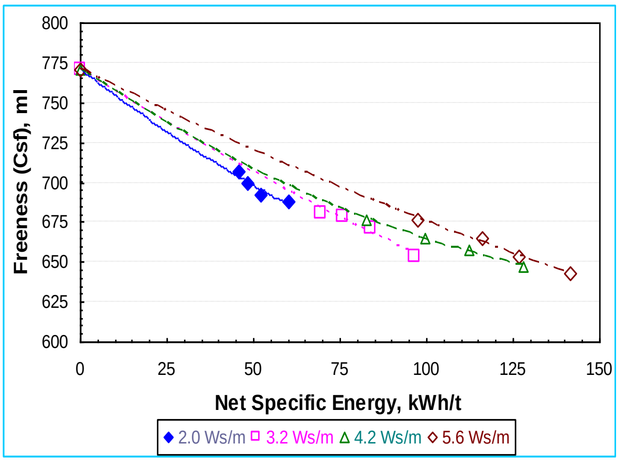

Fig 2 NSE vs. Csf at various SEL (Bottom Refiner)

Average fibre length (length weighted Average, LWA) values are shown in Figure 3. It can be seen from this graph that there was no significant difference in LWA fibre length when refined at 2.2 Ws/m and 3.1 Ws/m at a constant net specific energy of 90 kWh/t, suggesting minimal fibre cutting. Figure 4 shows similar plot for 'fines' (defined as LWA value less than 0.10 mm).

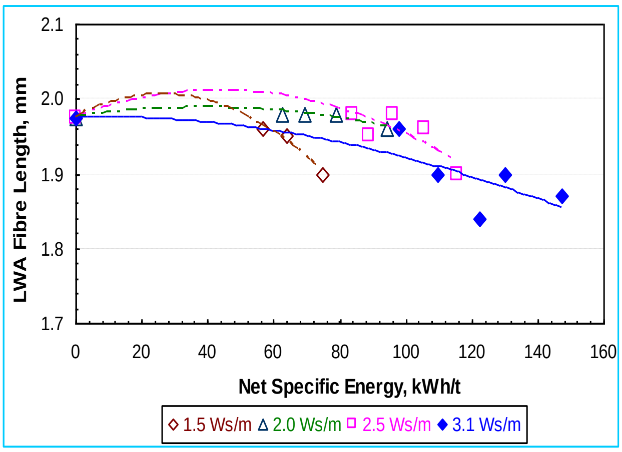

Fig. 3 NSE vs. LWA (Top Refiner)

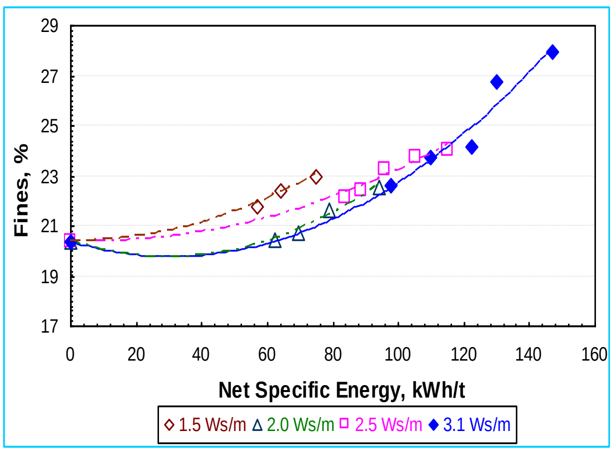

Fig 4 NSE vs. 'fines' (Top Refiner)

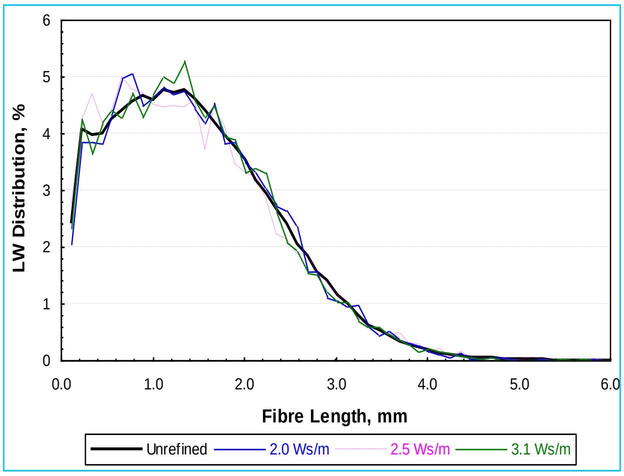

Fig. 5 FL Distribution at 96 kWh/t (Top Refiner)

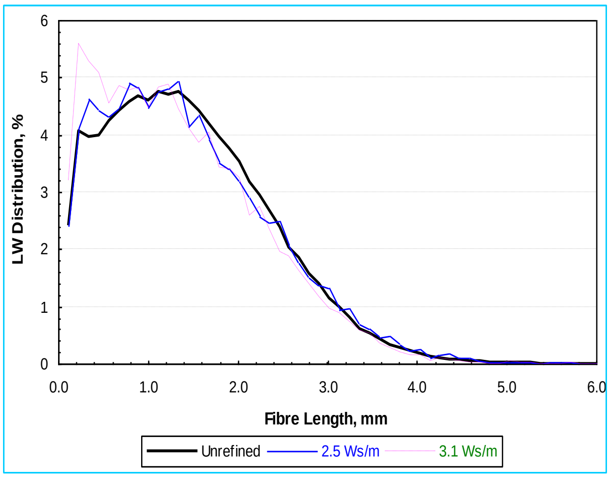

Fig 6 FL Distribution at 108 kWh/t (Top Refiner)

Figures 5 and 6 show the fibre length distribution at net specific energy of 98kWh/t and 108 kWh/t respectively for various refining intensity or SEL levels using the top wire refiner. The distribution curve of the unrefined pulp sample is also shown in these figures for comparison. It can be seen from Figures 5 and 6 that at lower SEL, the distribution curves of refined pulp samples are similar to that of the unrefined pulp. At 3.1 Ws/m refining intensity, particularly at 108 kWh/t net specific energy, the distribution curve shifted significantly towards the left with generation of more ‘fines’.

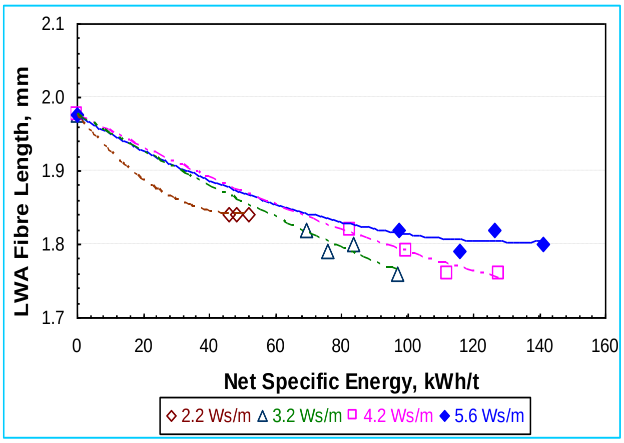

Fig. 7 NSE vs. LWA (Bottom Refiner – Mid Point)

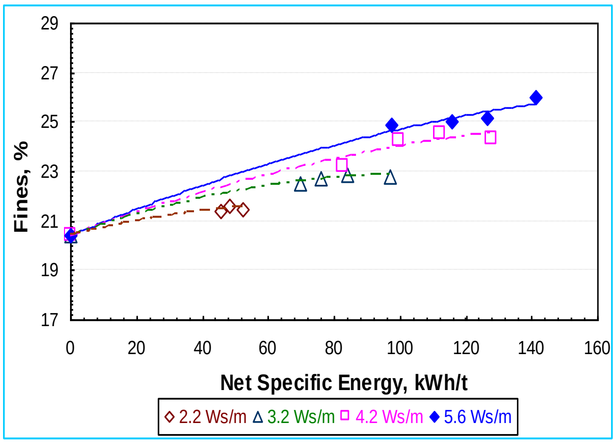

Fig 8 NSE vs. ‘fines’ (Bottom Refiner – Mid Point)

Fig. 9 FL Distribution at 98 kWh/t (Bottom Refiner)

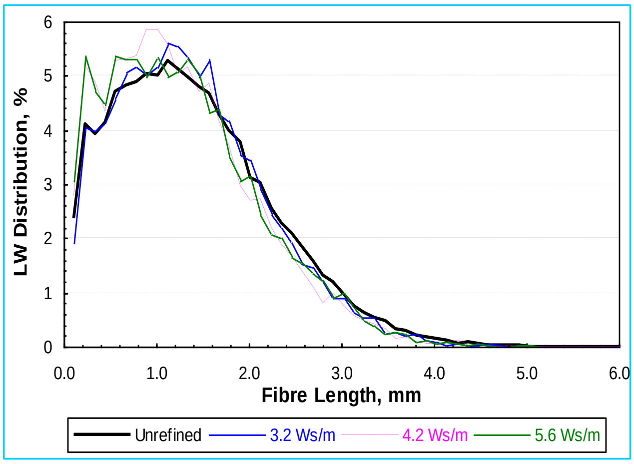

Fig 10 Micrograph (R1 Bottom, 5.6 Ws/m; 98 kWh/t)

Figure 7 shows the length-weighted average fibre length (LWA) values plotted as function of NSE at various SEL and refined on first of the two bottom line refiners (R1). Similar plots for ‘fines’ are shown in Figure 8. As expected, with increase in NSE at any SEL level, the LWA fibre length decreased. However, there was no evidence of fibre-cutting at higher refining intensity. This was reflected in higher LWA values at 5.6 Ws/m compared to that of 4.2 Ws/m and 3.2 Ws/m when compared at same net specific refining energy. The percentage of fibre ‘fines’ at higher refining intensities were also higher. These higher values were due to higher fibrillating effect at higher SEL, rather than fibre-cutting. Fibre length distribution of pulp refined at various SEL, but at constant net specific refining energy of 98 kWh/t is shown in Figure 9. It can be shown from this figure that at refining intensity of 4.2 and 5.6 Ws/m the distribution curve shifted significantly towards the left with generation of more fines.

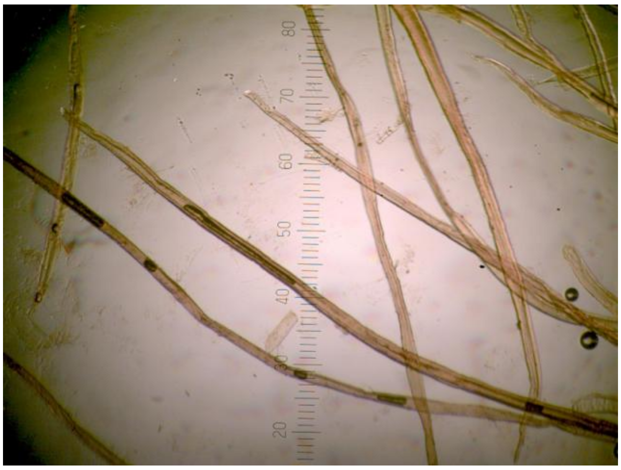

Fig 11 Micrograph (R1 Bottom, 3.2 Ws/m; 98 kWh/t)

Fig 12 Micrograph Top Refiner, 2.0 Ws/m; 98 kWh/t)

Micrograph of fibres refined at the first bottom refiner (R1) at 5.6 Ws/m refining intensity and 98 kWh/t, shown in Figure 10, suggests good fibrillation of the fibres at these refining conditions. Qualitative comparison of the effect of higher specific edge load on the level of fibrillation induced at constant net specific energy of 98 kWh/t can be seen from micrographs shown in Figures 11 and 12. These two micrographs are similar to that of the unrefined pulp shown in Figure 13. However, when refined at the same NSE (98 kWh/t) but at higher specific edge load of 5.6 Ws/m, presence of good fibrillated fibres are obvious in Figure 10. These observations suggest that high intensity refining of high-yield unbleached softwood pulp provides better fibre development.

Fig 13 Micrograph Unrefined Pulp

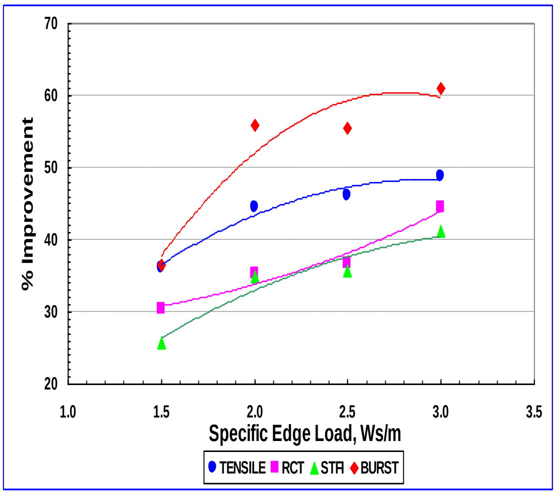

Fig. 14 Effect of SEL at 85 kWh/t (Top Refiner)

<u>Handsheet Properties</u>

Direct comparison of the effect of refining intensity on key strength properties (tensile, RCT, STFI and burst) of hand sheets made from refined pulp (top refiner) at constant net specific refining energy (85 kWh/t) is shown in Figure 14. Similar results at 110 kWh/t are shown in Figure 15. The percentage improvement values shown in this figure are with respect to the unrefined conditions and are generated from the plots of individual properties versus net specific energy at various SEL levels.

It can be seen from these two figures that the key strength properties increased with increase in refining intensity over the SEL range investigated. The refining intensity of the Top Wire refiner at the current snap shot operating condition is close to 2.0 Ws/m. If the refining intensity is increase from its current level to

3.1 Ws/m, the likely improvement with respect to the present level are: ring crush: 10 %; tensile: 13 %, burst: 12 % and STFI: 6 %.

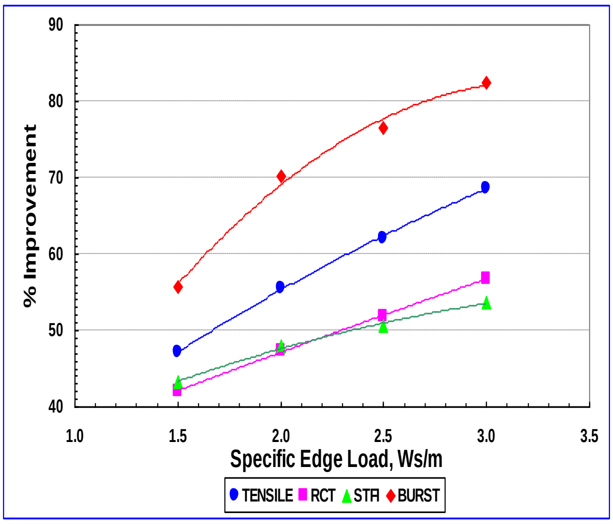

Fig. 15 Effect of SEL at 110 kWh/t (Top Refiner)

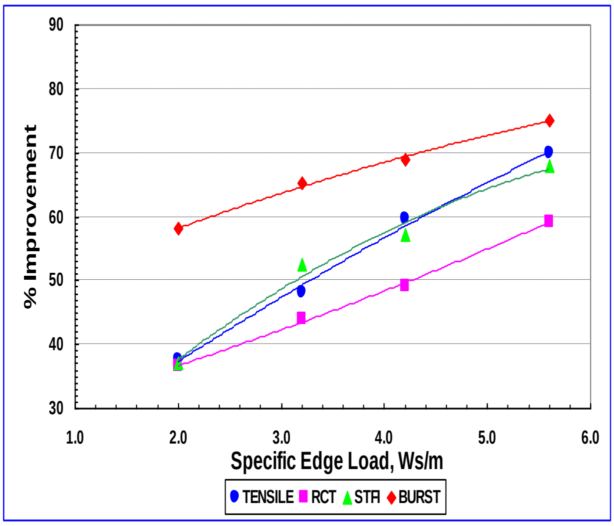

Fig. 16 Effect of SEL at 110 kWh/t (Bottom R1)

Figure 16 shows direct comparison of the effect of refining intensity of bottom R1 refiner on key strength properties of handsheet papers made from refined pulp. It is evident from this figure that the key strength properties increased with increase in refining intensity over the SEL range investigated. The refining intensity of the 1st Bottom Wire (also the 2nd Bottom Wire) refiner at the current snap shot operating condition is close to 3.8 Ws/m. If the refining intensity is increase from its current level to 5.6 Ws/m, the likely improvement with respect to the present level are: ring crush: 5 %; tensile: 20 %, burst: 10 % and STFI: 15 %.

Effect of Mode of Refining of Bottom Wire Refiners

The two bottom line refiners operating in series could be run at different modes such as (i) $(R1)_{High\ Intensity}$ followed by $(R2)_{Low\ Intensity}$; (ii) both R1 and R2 are of same intensity and (iii) $(R1)_{Low\ Intensity}$ followed by $(R2)_{High\ Intensity}$ with the total net specific energy of the two refiners being the same (170 kWh/t as used during the trial) in all such operating modes. The effects of such mode of operations on various properties of pulp freeness, fibre length and handsheet properties are discussed below.

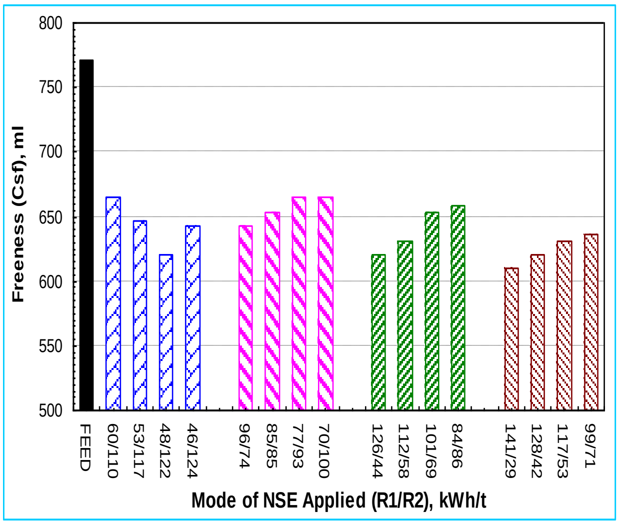

Fig. 17 Freeness Changes

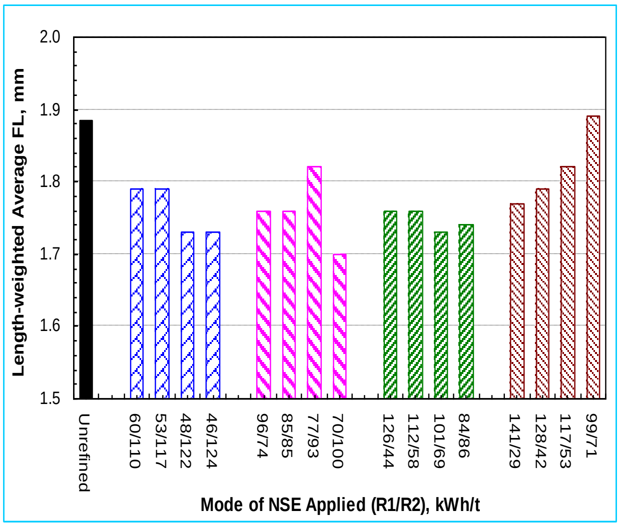

Fig 18 LWA Fibre Length

Figure 17 shows the freeness values of pulp samples at the exit of R2 refiner at various levels of refiner intensity used in the 1st bottom line refiner (R1) and at various split of total NSE between the two refiners. The current snap shot refining intensity of both the bottom wire refiners are 3.8 Ws/m (between 3.2 Ws/m and 4.2 Ws/m levels investigated and in both the cases, NSE split in both the refiners were close to 50/50). It is evident from this figure that the final freeness of pulp will be close to 40 Csf units lower if

$(R1)_{High\ Intensity}$ followed by $(R2)_{Low\ Intensity}$ strategy is used compared to current mode of operation. This relatively small decrease in freeness will be more than compensated by increase in key strength properties.

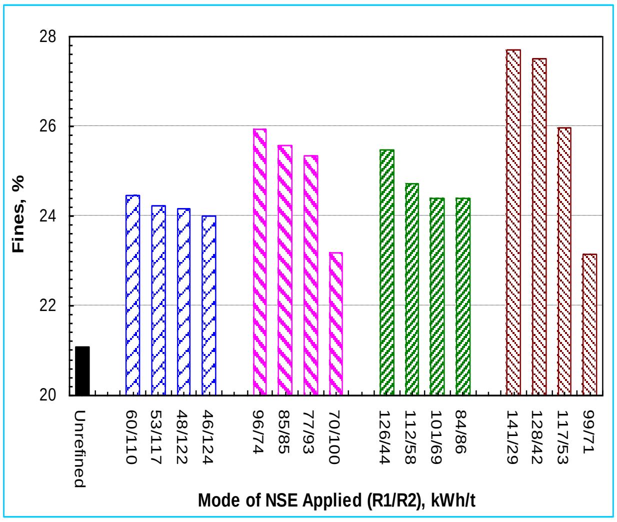

Fig. 19 Fibre Fines

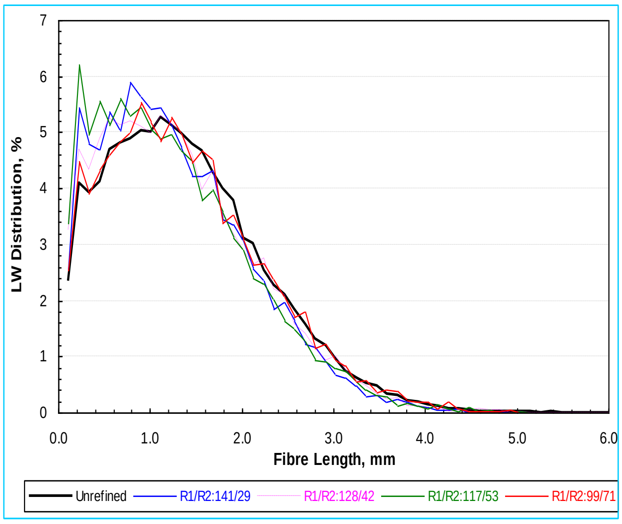

Fig 20 Fibre Length Distribution

Figures 18 and 19 show the 'fines' and LWA fibre length values of pulp samples at the exit of R2 bottom line refiner respectively at different split level of NSE amongst the two refiners. LWA fibre lengths were slightly decreased when R1 was subjected to high intensity refining followed by gentle refining on R2. The fines generation had the opposite effect i.e., highest amounts of fines were generated for such mode of operation. Decrease in LWA fibre length not necessarily suggests that fibre cutting occurred. A better representation is the fibre length distribution and is shown in Figure 20 when R1's refining intensity was 5.6 and that of R2 was 1.1 Ws/m. It can be seen from this figure that the percentage of fibres up to 1.2 mm length increased significantly compared to other mode of NSE splits. Figure 21 shows the micrograph of fibre from the exit of R2 Bottom Wire refiner with 140/30 split of NSE between R1 and R1. Very good fibrillation is clearly evident from this micrograph.

Figure 22 shows the summary, in terms of percentage changes, with respect to current mode of operation, of improvement if the 1st bottom line refiner is operated at high intensity followed by using the 2nd bottom line refiner as a polishing or trickle refiner. It can be seen from this figure that significant improvement in RCT (15%), tensile (21%), STFI (15%) and burst strength (20%) can be achieved, if 82% of total applied NSE is used or R1. Between 5% and 6% decrease in freeness (30 to 50 Csf drop) will occur for such mode of operation. Other minor detrimental effects will be slight decrease in colour parameters (L* decrease from 60.98 to 60.34, a* decrease from 7.65 to 7.59 and b* increase from 23.09 to 22.91).

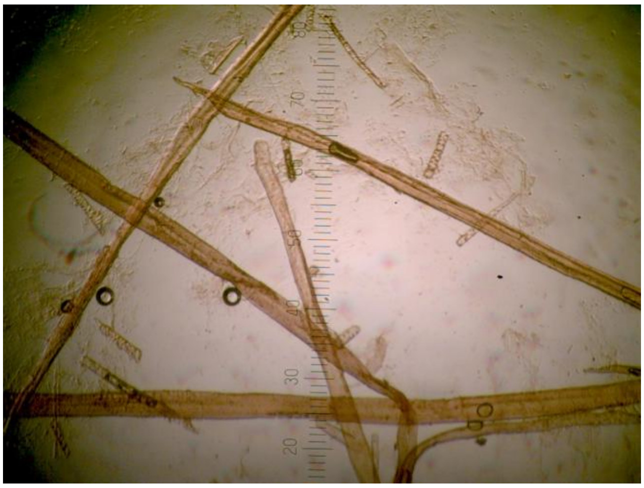

Fig 21 Micrograph : Effect of mode of refining

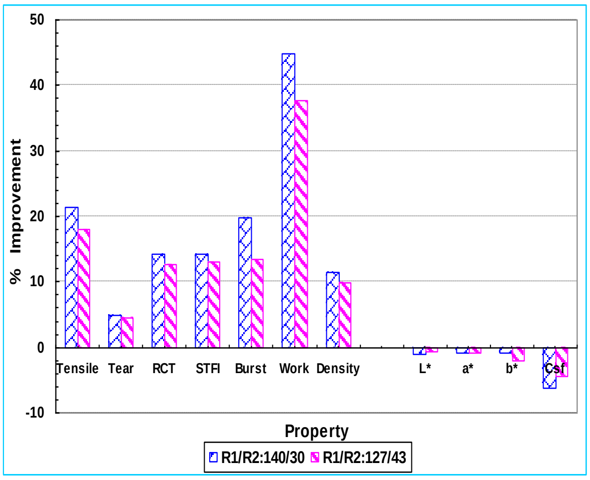

Fig 22 Percentage Changes : Effect of mode of refining

Conclusions

- Refining of high yield unbleached chemical softwood pulp at higher intensity is essential for better fibrillation and fibre development. At intensity level around 3.0 Ws/m, on-set of fibrillation occurs;
- For the pulp investigated, about 20% improvement in key strength properties (tensile, burst, STFI and ring crush compression strength) is achieved when refining intensity increased from 3.8 Ws/m to 5.6 Ws/m at constant net specific energy of 110 kWh/t;
- There are no evidence of occurrence of significant fibre-cutting when this type of pulp was refined at higher intensity;
- For two refiners operating in series, the optimal mode of operation is to use higher intensity at the first refiner followed by lower intensity at the second refiner at the total net specific energy applied to the pulps.

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APPENDIX

Definition of terms used in the Text

Specific edge load (SEL) or intensity of refining (Ws/m)

SEL = Net Power / Cutting Length per second

Net Power = (Applied Power – Idling Power), kW

Cutting Length = RPS*(n_s . n_r. L), km/s
RPS = Revolution Per Second
n_s = Number of moving bars
n_r = Number of stationary bars
L = Average length of one bar

Idling Load or No Load Power

Idling load or no-load power is defined as the power drawn by the refiner motor when the refiner plates are widest apart and the refiner motor was running at normal operating rpm with stock flowing through the refiner. The idling load could be measured or calculated. For a double disk refiner, the idling load can be calculated from the following equation:

Idling Load = $(2.299 * 10^{-13})*(D^{4.249})*(RPM^{3})$
D = Refiner Plate Diameter in inch
RPM = Refiner Rotor Speed (Motor Speed)

Net Specific Refining Energy (NSE)

NSE = Net Power/(Fibre flow, t/h)