Effect of Separate Refining and Co-refining of BCTMP/KP on Paper Properties

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Abstract: The effect of PFI separate refining and co-refining on paper properties was investigated for aspen bleached CTMP (BCTMP) and eucalyptus kraft pulp (EKP). The results showed that for a given freeness, separate BCTMP/EKP PFI refining required more energy than BCTMP/EKP co-refining; compared with BCTMP/EKP separate refining, BCTMP/EKP co-refining produced handsheets with improved surface smoothness and physical strength, while there was no significant difference in opacity and light scattering between these two refining processes. The results indicate that, in paper mill practice, it is possible to choose an appropriate addition level of BCTMP in KP and an appropriate refining process to maintain acceptable paper bulk and paper smoothness.

During the last decades, bleached chemi-thermomechanical pulp (BCTMP), also called high-yield pulp (HYP), has attracted an increasing amount of interest among papermakers in order to reduce costs and improve the quality of wood-free printing and writing paper [1, 2]. In the HYP process, pulps are produced mainly through a mild chemical treatment and the action of mechanical forces, with a yield of 80-90% and retention of most of the lignin in the wood [3]. Compared with chemical pulps, e.g. kraft pulp (KP), HYP contains a higher content of fines. HYP fibres are rigid, coarse, and cannot easily collapse. These differences between HYP and KP can result in different paper properties. Paper from HYP normally has higher bulk, bending stiffness, and dimensionally stability. The light scattering power, opacity, and printability obtained from HYP are also superior to those from chemical pulps mainly because of the higher amount of fines in HYP. Due to these specific attributes, HYP has been used in a variety of paper grades to reduce production cost and improve paper quality [4].

The high bulk of HYP can be used to reduce the basis weight at a given caliper in wood-free printing and writing papers. Higher bulk also increases paper stiffness at a given basis weight, high fines of content and the HYP may also improve sheet formation. In addition, the higher opacity of HYP provides optical benefits, particularly in lightweight specialty grades, such as lightweight coated (LWC) paper.

In recent years, the focus on HYP production and product development has been moving towards optimizing the process to tailor-make HYP with some specific pulp properties for a specific end-use in paper and board, particularly in the production of wood-free papers. In wood-free papers, such as LWC and printing and writing paper grades, HYP is used to replace hardwood kraft pulp and gives the final sheets higher bulk and opacity. The typical substitution rate of HYP in KP is 5 to 15% for coated and 10 to 25% for uncoated paper grades.

Although the bulk and opacity improvement can be achieved by the addition of HYP, the paper surface smoothness may be affected. Previous studies [5, 6, 7] indicated that thick-walled and
coarse HYP fibres may not only deteriorate paper surface smoothness but may also cause surface roughening upon rewetting in the printing process. To compensate the surface smoothness loss caused by the addition of HYP and to improve paper printability, HYP should be fine-tuned to tailor-make final product qualities. In mill practice, further refining of HYP is quite often employed to reduce the fibre coarseness in the mixed furnish. In some mills, hardwood KP is refined to about 400 mL CSF, and HYP is mixed in hardwood KP without refining, which is referred to separate refining as in this paper. In other paper mills, HYP is co-refined with hardwood KP.

The issue of separate or co-refining a mixed furnish of kraft pulps has drawn considerable attention amongst researchers and papermakers [8, 9, 10, 11], since the fibre characteristics of each type of pulp are quite often significantly different. It is difficult to conclude whether separate refining or co-refining provides better quality of the finished product. The method of refining a mixed furnish to achieve an optimal product quality is largely dependent upon the individual components of the furnish, e.g. HYP and kraft pulp, the furnish composition, e.g. percentage of HYP and kraft pulp in the furnish, and the pulp species, e.g. aspen KP or eucalyptus KP. In addition, some investigations revealed that for a given tensile strength, the energy efficiency and equipment investment between separate refining and co-refining were significantly different [12, 13].

Most published works on the comparison of separate refining and co-refining were based on hardwood and softwood kraft pulps. There is little published data in the literature on separate refining and co-refining of HYP and KP. In this study, the effect of separate refining and co-refining of aspen BCTMP and eucalyptus KP is investigated. The influence of the BCTMP substitution ratio on paper physical strength and surface smoothness are discussed.

EXPERIMENTAL

Materials

Aspen BCTMP 325/85 from a Canadian pulp mill and a bleached eucalyptus kraft pulp (EKP) from a French pulp mill were used in this investigation.

Refining

For separate refining, EKP was refined with a PFI mill to 480, 450, 400 and 350 ml CSF, and then mixed with 10% and 20% aspen BCTMP, respectively. For co-refining, EKP was mixed with 10% and 20% aspen BCTMP, and then refined with a PFI mill to CSF of 480, 450, 400 and 350 ml, respectively. For convenience, a short form ID was given to each pulp sample and different refining process, as listed in Table I.

Handsheet making and paper property measurement

Handsheets of a basis weight of 60±2 g/m² (o.d.) were prepared according to TAPPI standard (T205 sp-02). The thickness of the handsheets was measured with an L&W micrometer, and paper bulk was calculated based on the weight of handsheet. The tensile strength of the handsheets were tested with a tensile strength tester by L&W. Opacity, brightness, and light scattering were measured with a TechniBrite Micro-1c tester. Roughness was measured with a Parker surf tester, and internal bond was tested by a TMI station (Model 80-01-03). All the measurements were conducted according to the relevant TAPPI standard methods.

SEM analysis of paper surface characteristics

A Jeol JSM-6400 scanning electronic microscope (SEM) was used to study the fibre morphology characteristics of the paper surfaces and cross-sections; the handsheets were coated with carbon and gold before the surface observation. The cross-section was obtained as per the fol-
RESULTS AND DISCUSSION

Basic properties of EKP and BCTMP
The basic properties of eucalyptus KP (EKP) and aspen BCTMP are summarized in Table II. Aspen BCTMP pulp has higher opacity (80.5%) than EKP (75.8%), which is mainly due to the higher fines content in the pulp (23.1% vs. 10.0%). The coarseness of aspen BCTMP (0.174 g/m) is almost twice as high as that of EKP (0.095 g/m). Coarser fibres render aspen BCTMP pulp higher in bulk (2.48 cm³/g) than the EKP (1.83 cm³/g), which is the reason for BCTMP to be a partial substitute for KP to improve paper bulk. However, the higher coarseness of BCTMP pulp results in higher sheet roughness than the EKP pulp (7.02 µm vs. 5.67 µm).

The physical strength is also different between BCTMP pulp and EKP pulp. Compared with EKP pulp, BCTMP has lower tensile index (17.88 N.m/g vs. 28.06 N.m/g) which is mainly attributed to its coarser, shorter and stiffer fibres [14].

The above comparisons indicate that EKP and BCTMP pulps have significant differences in physical and optical properties. Therefore, it is reasonable to achieve desired paper properties such as higher bulk and better opacity by way of mixing a certain quantity BCTMP with KP [15].

Paper physical properties
Bulk and roughness
Paper bulk is dependent, to some extent, on the fibre components in the network, and coarser fibres render higher bulk [16, 17]. For a given bulk, the fibre consumption is lower when using coarser fibres, as a result, the production cost is reduced.

Figure 1 shows how the handsheet bulk properties developed for different pulp furnish. In comparison with the EKP pulp, the bulk in a blend furnish of BCTMP/EKP was improved in either separate refining or co-refining, which was mainly due to the coarser and stiffer BCTMP fibres in the furnish. A higher substitution ratio (20%) of BCTMP results in higher bulk. For the same substitution ratio, separate refining and co-refining bring about different results. With separate refining, the average bulk gain (20%) of 20%BCTMP/80%EKP was almost two times higher than that of co-refining (7%). In the separate refining process, BCTMP was mixed with EKP without refining, therefore, the intact BCTMP fibres contribute more to bulk than when refined with EKP.

Figure 2 shows that the influence of BCTMP on paper surface roughness depends on its addition levels, especially in the case of separate refining. In comparison with EKP, the blend furnish produced sheets with higher roughness in either separate refining or co-refining. As mentioned above, the BCTMP fibres are coarser and stiffer, which not only contribute to the bulk gain but also negatively affect paper smoothness. In addition, in both refining processes, higher addition (20%) of BCTMP gives the sheet higher roughness.

Interestingly, compared with the EKP, the roughness increase of co-refining BCTMP/EKP was not significant, especially in the case of Co-Re 10%BCTMP/90%EKP. A possible explanation is that in the case of co-refining, BCTMP fibres were modified by the refining process, which gives the sheet lower roughness. This indicates that with a substitution ratio of 10 to 20%, co-refining of BCTMP/KP can achieve similar roughness as 100% KP furnish.

Physical strength
At a given freeness, although separate refining of BCTMP/EKP had a positive effect on paper bulk and produced acceptable roughness, the physical strength of the sheets was lower, as shown in Figs. 3 and 4. In Fig. 3, for the blends of 10% BCTMP/90%EKP, the average loss of tensile strength was 6% in the separate refining, while it was 4% for co-refining. Additional blends (moving from 10% to 20%) had significant effects on the tensile strength: 14% for both separate refining and co-refining.

It should be noted that these findings are contradictory with the previous studies: adding a certain HYP (10 to 15%) in KP did not necessarily weaken the paper’s physical strength in disk refining [1]. The possible explanations might include the differences in the refining effects on pulp fibres between the lab PFI mill and disk refiner. In a comparative study between PFI mill and commercial refiners in refining energy, refining intensity, and other factors governing action on pulp, Kerekes and others [18, 19] indicated that the PFI mill is a high energy, low intensity refining device which produces a refining effect that differs significantly from a disk refiner in paper mills. As a result, the pulp fibres refined in a PFI mill revealed higher internal fibrillation, lower external fibrillation, and fibre shortening, which are mainly due to the fact that the PFI mill imposes a greater proportion of compressive to shear.
forces than an industrial refiner. Therefore, for a given freeness, the sheet physical strength produced in PFI mill may be inferior to those in disk refiner.

Similar trends can be observed in the relation of freeness to internal bond, as shown in Fig. 4. The decrease of the internal bond in co-refined BCTMP/EKP was less important than in the case of separate refining. In co-refining, BCTMP fibres were modified by splitting, delaminating, and unraveling actions of mechanical refining, which were favourable for the bonding potential of fibres. Compared with the un-treated BCTMP fibres in separate refining, the refined BCTMP in co-refining contributes more to the paper’s physical strength, i.e. internal bond.

In addition, to get the same internal bond from different pulp furnish, a different required freeness. For example, to achieve 300 J/m², EKP, Co-Re 10%BCTMP/90%EKP, and Co-Re 20%BCTMP/80%EKP were intended to refine to 400, 350, 370 mL CSF, respectively. These may suggest that mixing BCTMP in EKP furnish needs more refining energy to get the same physical strength as that of the individual EKP refining. With a higher percentage of KP being mixed in a BCTMP furnish, more energy is consumed.

The above analysis indicates that replacing KP with BCTMP would deteriorate the physical strength of final product, especially in the case of separate refining of BCTMP/KP. In mill practice, this disadvantage could be compensated for by process modification and development. For instance, with advancement and modernization in the design of paper machines, the web tolerance on paper’s physical strength would be largely improved. In addition, some new products which are less exigent on physical strength could be developed to fulfill different customer requirements.

**Optical properties**

As indicated in Table II, BCTMP contains a higher fraction of fines (23.1%) than EKP (10%). Compared with chemical pulp fibres, mechanical pulp fines have greater specific surface area owing to the abundant content of fibril-like and flake-like particles in the fines [20]. Fines have strong effects on the structures and properties of fibre networks, particularly rendering a high opacity and light scattering coefficient [21], which are favourable for printing and writing papers [22].

As expected, adding BCTMP to KP improved optical properties, such as opacity (Fig. 5) and light scattering coefficient (Fig. 6) compared with the EKP. Interestingly, for both opacity and light scattering, there was no significant difference between separate refining and co-refining processes. This finding suggests that the gain in the optical properties is dependent more on the nature (or grade) of the BCTMP, and less on their addition ratio, as reported in [1].

**SEM analysis**

Figures 7 and 8 show the surface characteristics of separate and co-refining of the same blend furnish: 20%BCTMP/80%EKP with the same freeness level (350 mL). These SEM images indicate that there is no significant difference between the top views of the surfaces. The relatively smooth EKP fibres and fibrillated BCT-
MP fibres were evenly distributed on the sheet surfaces. Although there is no evident fibre difference from the top-view surfaces between the separate refining and co-refining (Figs. 7 and 8), the SEM cross-sectioned view images (Figs. 9 and 10) revealed an apparent difference in surface roughness between these two refining processes. In separate refining, the sheet surface was uneven and some tube-like uncollapsed fibres were loosely combined together, which renders higher sheet bulk. In co-refining, the sheet surface showed relatively smooth and collapsed fibres which were tightly compacted, and resulted in lower paper bulk. This observation can explain the reason that the separate refining produced handsheets with higher bulk and roughness, but lower physical strength when compared with those of co-refining.

Refining energy
In this study, the PFI revolutions were used to evaluate pulp energy consumption in refining. Figure 11 shows the freeness development at different PFI mill revolutions. The initial freeness before refining was 680 ml for EKP and 570 ml for aspen BCTMP (Table II). After refining, the freeness-revolution curves (trends) were different among the different pulp furnishes. For a given freeness, higher energy consumption was found for BCTMP/EKP in a separate refining process than that of BCTMP/EKP in a co-refining process and EKP individual refining. In BCTMP/EKP separate refining, the freeness reduction was completely attributed to the EKP refining alone since the BCTMP was directly added into the EKP, after EKP refining, and suffered no subsequent refining action in the blend furnish. Therefore, for a given refining freeness, BCTMP/EKP separate refining consumes more energy than the EKP individual refining and BCTMP/EKP co-refining. Furthermore, in separate refining, a higher percentage of EKP replacement (20%) required more PFI revolutions to obtain the same freeness level than a lower percentage of replacement (10%).

It should be pointed out that for the BCTMP/EKP co-refining, although a different proportion (10% and 20%) of BCTMP was mixed in EKP, they had similar freeness/revolution trends as the EKP. This suggests that adding up to 20% of the aspen BCTMP to the EKP had no significant effect on the freeness development, compared with the EKP alone. This means that for a paper mill, replacing up to 20% of eucalyptus bleached KP with aspen BCTMP may not require a significant increase in energy consumption in the refining operation.

CONCLUSIONS
Partial substitution (10 to 20%) EKP with BCTMP would improve paper bulk, sheet opacity, and light scattering coefficient, however, physical strength would be reduced.

For a given freeness, compared with BCTMP/EKP separate refining, BCTMP/EKP co-refined produced handsheets with improved surface smoothness and physical strength, while there were no significant differences in opacity and light scattering between these two refining processes. A higher percentage of BCTMP in EKP resulted in higher bulk and higher roughness, but weakened physical strength. It is possible to choose an appropriate addition level of BCTMP in EKP and a refining process to maintain acceptable paper bulk and paper smoothness.

For a given freeness, BCTMP/EKP PFI separate refining required more energy than BCTMP/EKP co-refining.

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LITERATURE


Résumé: Nous avons analysé les effets sur les propriétés du papier de la séparation du co-raffinage et du raffinage sur PFI d’une pâte chimico-thermomécanique blanche (PCTMB) de tremble et d’une pâte kraft d’eucalyptus (PKE). Les résultats indiquent que, pour un degré d’égouttage donné, le raffinage séparé de la PCTMB et de la PKE exige davantage d’énergie que le co-raffinage de ces deux pâtes. Comparativement au raffinage séparé, le co-raffinage a produit des formenttes dont le lissé de la surface et la résistance physique étaient améliorés, tandis qu’il n’y avait pas de différence notable entre les deux procédés de raffinage en ce qui a trait à l’opacité et à la diffusion de la lumière. Les résultats indiquent que, en usine, il est possible d’ajouter une quantité appropriée de PCTMB dans la pâte kraft et de sélectionner un procédé de raffinage permettant de maintenir un papier doté d’un bouffant et d’un lissé acceptables.


Keywords: BCTMP, CHEMI-THERMO-MECHANICAL PULP, KRAFT PULP, KP, SEPARATE REFINING, CO-REFINING, PAPER PROPERTIES, HIGH-YIELD PULP.