NEW APPROACH TO USE OF KENAF FOR PAPER AND PAPERBOARD PRODUCTION

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This study sought to determine the suitability of fractionation and consequence-selective processing (separation of long fiber and short fiber, beating long fiber, and remixing with short fiber to target freeness) as a new approach to use of kenaf whole stem pulp for paper and paper-board production. A laboratory Bauer-McNett Classifier with screen 18 mesh was used to separate short fibers and long fibers of the unbeaten kenaf whole stem soda-anthraquinone high kappa and low kappa pulps. For comparison, the initial unbeaten pulps were beaten in the PFI mill to the same freeness (300 mL CSF). Results of our patented method showed that the fractionation process was able to provide a good opportunity to beat the long fiber portion at higher PFI revolutions and to achieve better fibrillation, significantly improving all paper properties of kenaf pulps except for tear index and producing sheets with better drainage and strength properties compared to conventionally beaten pulps, especially in the case of kenaf high kappa pulp.

Keywords: Kenaf; Fractionation; Beating; Drainage time; Strength properties

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INTRODUCTION

Kenaf (*Hibiscus cannabinus L.*) is a herbaceous annual plant of the Malvaceae family. Being a dicotyledon, kenaf stem contains two distinct fiber components the bast fiber and inner woody core that are significantly different in chemical and morphological properties. Generally, the bast part accounts for about 35% of stem mass, and a woody core part comprises the remainder. The bast fibers are long and slender with higher cellulose content, while the core fibers are much shorter and wider with higher lignin content (Abdul Khalil et al. 2010; Azizi Mossello et al. 2009). Because of their different nature and structure, the two types of fiber show different behavior during the papermaking process. Core pulp due to its low proportion of fiber and presence of components with a high surface area to mass ratio coming from pith (Villar et al. 2009) has low freeness and high susceptibility to refining action, so that the pulp rapidly attains freeness values that are quite prohibitive for practical purposes (Calabro 1992). These shortcoming restrict the use of core pulp, which is probably better used in an unrefined condition (Kaldor 1989). On the contrary, bast pulps refine easily and develop strength properties (Villar et al. 2009; Calabro 1992). Due to the difference in the quality of bast and core fiber, some researchers have proposed separation of core and bast, pulping, and using each pulp separately (Villar et al. 2009; Nezamoleslami et al. 1997; Ren et al. 1996; Calabro 1992; Kaldor 1989) or adjusting the ratio of their blending based on the final product properties that are required (Villar et al. 2009). On the other hand, there are advantages in using kenaf as a whole stem (bast and core together) for technical and economical reasons (Ververis et al. 2004; Khristova et al. 2002). It is critically important to find ways to overcome to these issues.

On the other hand, fiber fractionation processes, which utilize maximum potential of the fiber, are becoming increasing important in the paper industry (Sood et al. 2005). Fractionation is a process that separates a blend of fibers in pulp according to some physical property of the fibers such as length, flexibility, coarseness, etc. (Sood et al. 2005; Gooding and Olson 2001). Fractionation and consequent selective processing of furnish components offers potential to achieve raw material and energy efficiency (Branvall et al. 2005; Vomhoff and Grundstr 2003). The idea is to direct the right kind of fiber furnish, and only the right kind of fiber furnish, through the required processing, depending on its end use, so that it will generate the highest customer value. Many different scenarios have been practiced for fractionation in the pulp and paper industry (Sood et al. 2005; Olson 2001). One general approach is to fractionate fiber into long and short fiber portions, beat the long fiber portion, and then recombine the refined long fibers with the unrefined short fibers. The main objective of this study was to determine the effect of fractionation and consequent selective process on kenaf whole stem soda-anthraquinone (soda-AQ) pulp properties.

EXPERIMENTAL

Materials

Unbeaten kenaf whole stem soda-AQ pulps, i.e. kenaf high kappa (KHK) and kenaf low kappa (KLK) pulps (Table 1), were prepared from our earlier study (Azizi Mossello et al. 2010).

Table1. Soda-AQ Pulping Result for Kenaf Whole Stem

Pulp	Cooking condition		Pulp quality			
	A.A. (%)	Time (min)	Kappa no.	Lignin† (%)	Reject (%)	Total yield (%)
Kenaf high Kappa	12	60	49.4	7.41	1.8	58.0
Kenaf low Kappa	15	60	25.4	3.82	0.2	54.9

A.A.- active aclkali as Na_2O; Cooking temperature, 160 ºC; liquor to raw material ratio, 7:1; AQ, 0.1% (on oven dried chips basis)

† Lignin content =0.15× Kappa no. (Ren et al., 1996)

Methods

Fractionation and consequent selective process

Based on length of the kenaf bast (2.39 ± 0.43) and core (0.72 ± 0.17) fibers (Azizi Mossello et al. 2009), a laboratory Bauer-McNett Classifier (BMC) with screen 18 mesh size (1mm) was used to separate long and short fibers of kenaf whole stem pulps according to TAPPI T 233 cm-95 at the pulp and paper laboratory in Forest Research Institute Malaysia (FRIM). For each run, about 3500 mL of 0.3% pulp suspension was poured into the first chamber. A continuous flow of water passes through this chamber. The short fraction passed the screen and was collected on a very fine screen (200 mesh). After 20 min, the flow was stopped, the chamber was drained, and the long-fiber fraction was collected. After that, each fraction was collected and span-dried, and the moisture contents were determined according TAPPI T210 cm-93. The long-fiber fractions were beaten with a PFI mill according TAPPI T 248 sp-00 and remixed with unbeaten short-fiber fractions (recreation the initial pulps) to reach a freeness of 300 mL CSF and termed recombined pulps, i.e. recombined kenaf high kappa (RKHK) and recombined kenaf low kappa (RKLK). The kenaf high Kappa (KHK), and low Kappa (KLK) pulps were beaten separately in a PFI mill at the same freeness level i.e. 300 mL CSF and designated as beaten kenaf high Kappa (BKHK) and beaten kenaf low Kappa (BKLK) pulps respectively.

Fiber dimensions and derived values

The pulp samples designated as KHK, KLK, BKHK, BKLK, RKHK, and RKLK, were boiled in water in separate beakers to remove air from the fibers and then placed in separate test tubes containing an equal amount of glacial acetic acid and 35% hydrogen peroxide, an approach similar to that followed by Franklin (1945). For this study, fiber length (L), fiber diameter (D), lumen diameter (d), and cell wall thickness (w) were measured based on an average of 50 measurements by using a Quantimeter Image Analyzer equipped with a Lecia microscope and Hipad digitizer (from Quantimet 520, Cambridge Instruments). Three derived values: slenderness ratio (L/D), flexibility coefficient($100 \times d/D$), and Runkel ratio ($2 \times w/d$), were calculated using the measured data.

Fiber classification

The fiber classification for each pulp was carried out with a Bauer-McNett Classifier (BMC) with 4 screens (18, 40, 70, and 140 mesh) according to TAPPI T 233 cm-95 with 3 replications.

Paper characterization

The drainage times of the pulps were determined according to T 221 cm-99. The handsheets with basis weight of 150 g/m^2 were made in a British handsheet former according to TAPPI T 205 sp-02 and tested for tear index (TAPPI T 414 om-98), tensile index (TAPPI T 494 om-01), burst index (TAPPI T 403 om-97), and ring crush test(RCT) (TAPPI T 822 om-02). Light scattering coefficient was measured using a Color Touch^{TM} model ISO (Technidyne Corporation) spectrophotometer according to TAPPI T425 om-01. The surface morphology of pulp fibers was observed using a

Philips XL30 ESEM at the electron microscopy unit in the Institute of Bio-Science (IBS) at University Putra Malaysia (UPM).

Statistical analysis

The fiber and paper properties experiments were done as a Completely Randomized Design (CRD) with 6 pulp types as treatment. Analysis of variance and Duncan multiple Range tests were done to show difference between treatments. Statistical procedures were carried out using SPSS software.

RESULTS AND DISCUSSION

Fractionation and Recombination

Table 2 shows the fractionation results of kenaf whole stem soda–AQ pulps. It can be seen that KLK had higher long fiber (47.59 vs. 41.19 %) and lower short fiber (52.41 vs. 58.81) than KHK. According to Calabro (1992), at low soda concentration, yield is greater for core, but with higher concentration of soda it inverts and become greater for the bast. Also, Mittal and Maheswari (1994) based on their experience with commercial kraft pulping of whole kenaf stalk in Thailand (Phoenix Paper Mill) reported that during the process of pulping, a higher portion of bast fibers remain with the final pulp, which resulted in higher average fiber length and good strength properties of the final pulp sheets. Again, in contrast to short fiber, long fiber due to higher freeness, had higher potential for beating

Table 2. Fractionation Results for Kenaf Whole Stem Soda-AQ Pulps

Parameter	unit	KHK		KLK	
		Long fiber	Short fiber	Long fiber	Short fiber
Mass split ratio	%	41.19	58.81	47.59	52.41
Length	mm	2.25	0.63	2.43	0.60
freeness	mL CSF	590	346	568	319

Figure 1 illustrates the pulp freeness development as a function of the number of PFI mill revolutions for the kenaf pulps. In comparison to beaten pulps, recombined pulps required more beating to reach a same freeness. For instance, RKHK required higher PFI revolutions than KHK (2500 vs. 700) to reach a freeness of 300 mL CSF, and RKLK took higher beating than KLK (2000 vs. 950) to reach a freeness level of 300 mL CSF. These results show that fractionation can provide a good opportunity to beat the long fiber portion at higher PFI revolutions and remix those refined fibers with short fiber pulps to reach the same freeness. Also, RKHK pulp, due to its higher lignin content than RKLK (7.41 vs.3.82%), had lower swellability and beatabillity (Steh 2001) and required more beating to reach a target freeness.

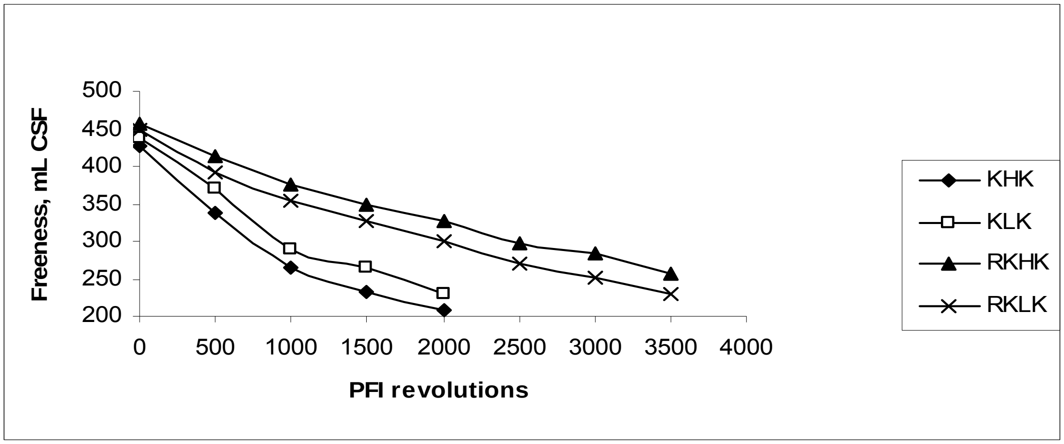

Figure 1: Variation of kenaf soda-AQ pulps freeness with PFI mill revolutions

Fiber dimension and derived values

The fiber dimension results are given in Table 3. In comparison to KHK, KLK probably due to higher percentage of long fiber (Table 2) had a higher average fiber length, but lower fiber diameter, as well as lumen and cell wall thickness. Beating decreased all fiber dimensions (Rushdan 2003) (Figure 2). BKHK, because of lower beating, showed a smaller decrease in fiber dimensions. In comparison to beating pulps (BKHK and BKLK), recombined pulps (RKHK and RKLK), and due to higher beating, had larger decreases in fiber dimensions except for lumen diameter. Again, RKLK showed a higher fiber length (1.39 vs. 1.27 mm) and lower cell wall thickness (3.05 vs. 3.21 µm) than RKHK.

Table 3. Fiber Dimensions of Kenaf Whole Soda-AQ Pulps

Pulp	Length, mm	Diameter, µm	Lumen, µm	Thickness, µm
KHK	1.50ab†	21.03a	13.20a	4.16a
BKHK	1.38b	19.95ab	12.97a	3.97a
RKHK	1.27b	18.75bc	13.10a	3.21b
KLK	1.69a	19.42b	12.70a	3.90a
BKLK	1.46b	18.01c	11.96a	3.44b
RKLH	1.39b	17.59c	12.51a	3.05b

† Means within a column followed by different letters differ significantly at $\alpha = 0.05$

Derived values of kenaf whole stem soda-AQ pulps are shown in Table 4. In comparison to KHK, KLK pulp had a higher slenderness ratio (87.02 vs. 71.33) but the same flexibility coefficient and Runkel ratio. Beating with fibrillation and fiber shortening (Table 2 and Figure 2) decreased the slenderness ratio and Runkel ratio but increased the flexibility coefficient of pulps. In comparison to beaten pulps, recombined pulps showed higher decreases in Runkel ratio (about 19 vs. 5%) and had the lowest Runkel ratio (0.49), which can be explained as due to better fibrillation of long fiber at higher PFI revolutions (see Figs. 1 and 2).

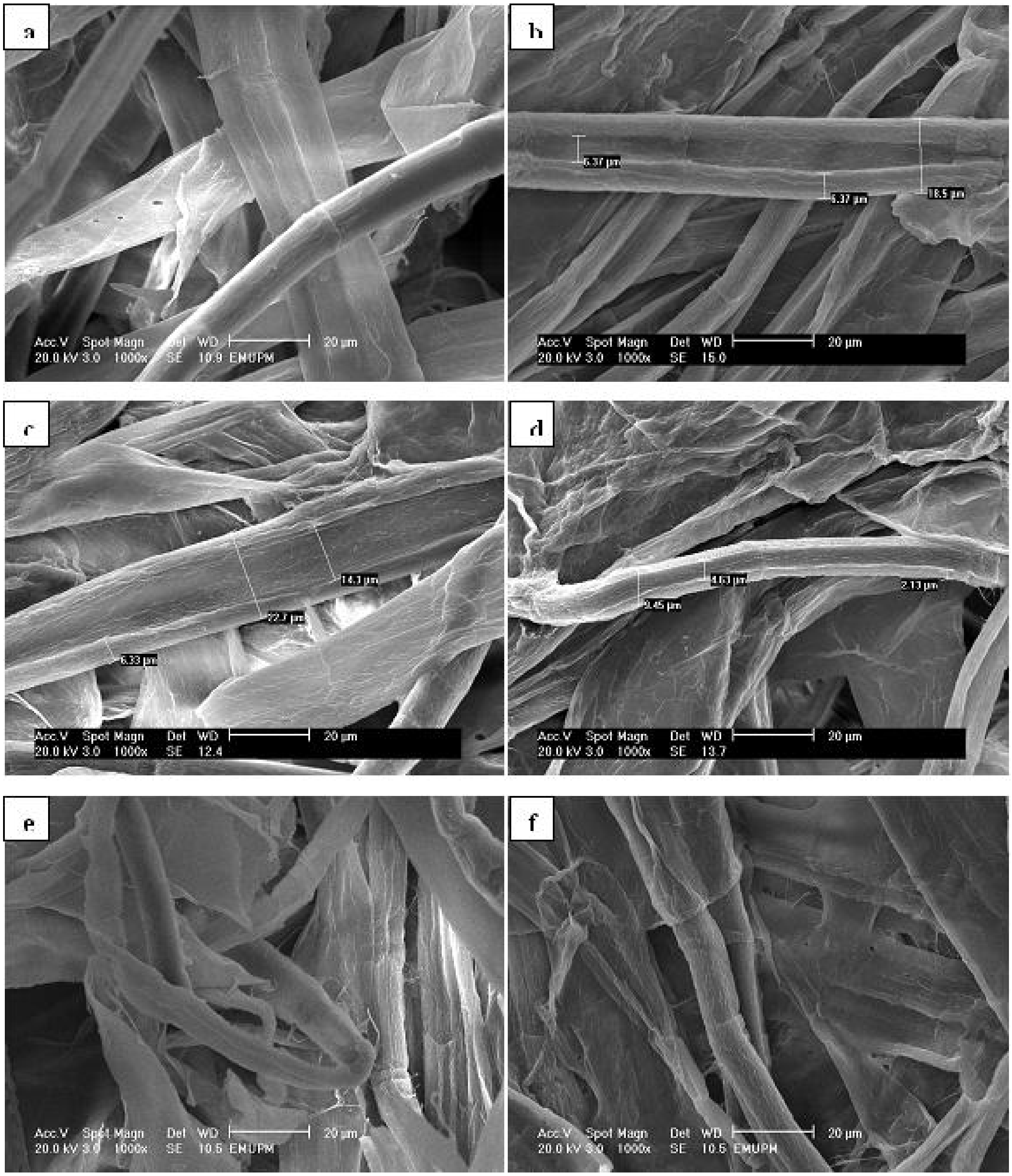

Figure 2. ESEM micrographs kenaf soda-AQ pulps fibers with magnification 1000x: (a) unbeaten kenaf high kappa pulp(KHK), (b) unbeaten kenaf low kappa pulp (KLK), (c) beaten kenaf high kappa pulp (BKHK), (d) beaten kenaf low kappa pulp (BKLK), (d) recombined kenaf high kappa (RKHK), (e) recombined kenaf low kappa (RKLK)

Table 4. Derived Values for Kenaf Whole Soda-AQ Pulps

Pulp	Slenderness ratio	Flexibility coefficient	Runkel ratio
KHK	71.33	62.77	0.63
BKHK	69.17	65.01	0.61
RKHK	67.73	69.87	0.49
KLK	87.02	65.40	0.61
BKLK	81.07	66.40	0.58
RKLH	79.02	71.12	0.49

Bauer-McNett Fiber classification

The results for Bauer-McNett fiber classification of kenaf whole stem soda-AQ pulps are shown in Table 5. It can be seen that KLK contained significantly more R18 fiber and less R40 fiber mass, but almost the same amounts of R70, R140, and P140 fibers, which means that KLK contained higher long fiber, in good agreement with fractionation results that showed a higher percentage of long fiber for KLK (see Table2). Beating significantly decreased R18 fiber. Recombined pulps showed higher decreases in R18 fiber than beating pulps. Again, RKHK showed the highest decreases in R18 fibers. Beating caused decreases in R40 and R70 fibers of beaten pulps, but caused increases in R40 and R70 fiber of recombination pulps. Also, beating, due to fines generation, significantly increased the amount of P140 fibers. From Table 4 it can be seen that there were no significant differences between recombined pulps and BKHK for P140 fibers, but BKLK had a significantly higher amount of P140 fibers. It can be explained that beating, in case of kenaf whole pulps, had a greater effect on short fiber, but in case of recombined pulps, beating long fibers provided a good opportunity to achieve better fibrillation (Fig. 2), which is clearly documented by the lower Runkel ratio in Table 4.

Table 5. Bauer-McNett Fiber Classification of Kenaf Pulps

Pulp	R18, %	R40, %	R70, %	R140, %	P140, %
KHK	39.01b[†]	22.17b	12.63a	5.15ab	21.04c
BKHK	36.76c	18.22c	11.90ab	6.26a	26.83b
RKHK	27.29d	24.83a	13.10a	5.74ab	29.01ab
KLK	45.19a	18.80c	11.89ab	4.60b	19.52c
BKLK	39.13b	13.10d	10.39c	6.53a	30.83a
RKLH	35.43c	20.16c	12.38a	4.79b	27.25b

[†] Means within a column followed by different letters differ significantly at $\alpha = 0.05$

Handsheet properties of kenaf whole stem soda-AQ pulps

Table 6 shows the properties of handsheets made from unbeaten (KHK and KLK), beaten (BKHK and BKLK), and recombined (RKHK and RKLK) kenaf whole stem pulps. It can be seen that beating, due to fiber shortening and fines generation (Tables 3 and 5), significantly increased the drainage time of pulps. There was no significant difference between recombined pulps and BKHK, but BKLK had significantly higher drainage time than other pulps. It is a very interesting point that except for the higher beating of long fiber of the recombined pulps, they showed almost the same or lower drainage time than beaten pulps.

Apparent density is among the most important properties of paper, since is a good indicator of fiber flexibility and fiber bonding (Seth 2001; Brandon 1981) and is used by some as a predictor of paper strength, since bonding in the sheet increases both strength and density (Kline 1982). In the case of unbeaten pulps, KLK had significantly higher density than KHK due to more flexible fibers and easier collapsability that is associated with lower lignin content. Beating significantly increased the density of the pulps (Table 6). Recombined pulps showed higher density than beaten pulps, which showed more flexible fibers (see Fig. 2), as indicated by a lower Runkel ratio (Table 4).

Table 6. Handsheet Properties Made from Kenaf Soda-AQ Pulps

Parameter	KHK	BKHK	RKHK	KLK	BKLK	RKLK
Drainage time, s	7.75d†	10.40b	10.82ab	8.49c	11.05a	10.55b
Apparent density, g/cm^3	0.590e	0.651c	0.690ab	0.620d	0.672bc	0.705a
Light scattering coefficient, m^2/kg	24.90a	22.56b	19.13cd	22.83b	20.06c	18.05d
Tear index, $mN.m^2/g$	13.38c	14.35b	13.09c	15.11a	14.36b	13.91b
Tensile index, N.m/g	71.03d	78.23c	87.52b	78.84c	86.10b	93.11a
Burst index, $kPa.m^2/g$	4.18d	5.21c	6.10b	5.12c	5.90b	6.59a
RCT, kN/m	1.85e	2.25d	2.87b	2.25d	2.68c	3.11a

† Means within a row followed by different letters differ significantly at $\alpha = 0.05$

The light scattering indirectly indicates unbonded area between the component fibers, thereby providing an inverse estimated degree of bonding (Seth 2001; Clark 1985). KLK exhibited more flexibility of the fiber due to lower lignin higher fiber bonding than KHK, as indicated by a lower light scattering coefficient (Table 6). Beating significantly decreased the light scattering coefficient. Recombined pulps showed lower light scattering coefficient than beaten pulps. BKHK and KLK showed almost as same light scattering coefficient.

Tear strength depends on fiber length, fiber bonding, and the total number of fibers that are involved in the sheet rupture. The number of fibers participating in the sheet rupture is determined by the flexibility of the sheet. A rigid sheet will concentrate the force on a few fibers in a small area; a flexible sheet will distribute the force over a much larger area and, therefore, a larger number of fibers. The force required to tear paper is much less than the force necessary to break a strip of the paper. Moreover in a weakly bonded sheet, since more fibers pull out than break in the tear zone, the tearing resistance is controlled more by the number of bonds that break along the length of the fibers; thus tearing resistance depends strongly on the fiber length (Institute of Paper Chemistry Staff 1944). According to Table 6, KLK due to higher fiber bonding, as indicated by higher density and lower light scattering coefficient, had higher tear index than KHK. With the exception of BKHK, beating decreased tear index of pulps. This can be explained, since under the condition of tightly bonded fibers, more fiber are ruptured through the initial cut, and fiber rupture requires less energy than pulling fibers out from network, so tear strength is reduced (Institute of Paper Chemistry Staff 1944).

Tensile strength and burst index are dependent on fiber bonding (Dutt et al. 2009; Jahan and Rawshan 2009) and showed similar trends in this study. KHK showed significantly lower tensile index and burst index than KLK. Beating increased the tensile index and burst index of the pulps. At the same freeness, recombined pulps showed higher tensile index and burst index than beaten pulps (Table 6). BKHK and KLK achieved the same tensile index and burst index. Again, BKLK and RKHK reached almost the same tensile index and burst index. RKLK showed significantly higher tensile index and burst index than other pulps, which can be explained as due to better fibrillation and improvement of fiber bonding. This was indicated by lower light scattering coefficient and higher sheet density, as explained earlier.

The ring crush test (RCT) is used extensively for quality control during production of linerboard and corrugating medium. Fiber with better bonding can produce paper with higher ring crush strength (Parker et al. 2005). From Table 6 it can be seen that KLK had higher RCT than KHK. Beating significantly improved the RCT of the pulps. Again, recombined pulps achieved significantly higher RCT than beaten pulps at same freeness. BKHK and KLK had the same RCT. RKLH had a significantly higher RCT than the other pulps considered.

CONCLUSIONS

The fractionation results showed that kenaf low kappa (KLK) had higher long fiber and lower short fiber than kenaf high kappa (KHK) pulp. Long fibers, because of their higher freeness, have potential to be beaten and improve strength properties. In comparison to beaten pulps, recombined pulps required more beating to reach the same freeness. So, fractionation provides a good opportunity to beat the long fiber more extensively and remix them with short fiber pulps to reach the same freeness. Also, the recombined high kappa (RKHK) pulp, due to its higher lignin content than RKLK, had lower swellability and beatabillity and required more beating to reach a target freeness.

Beating with shorting and fibrillation decreased all fiber dimensions. Recombined pulps (RKHK and RKLK), due to higher beating, had larger decreases in fiber dimensions, with the exception of lumen diameter. Moreover, recombined pulps showed lower Runkel ratio than beaten pulps.

Beating affected the fiber distribution of pulps. Recombined pulps showed greater decreases in R18 fiber than beaten pulps. Beating caused decreases in R40 and R70 fiber fractions of beaten pulps, but caused increases of R40 and R70 fiber fractions in recombined pulps. Beating, due to fines generation, significantly increased P140 fibers, but there were no significant differences between recombined pulps and BKHK for P140 fibers; BKLK had a significantly higher amount of P140 fibers.

Beating with fiber shortening, fibrillation, and fines generation improved fiber bonding, as indicated by lower light scattering and higher paper density. In comparison to beaten pulps, recombined pulp produced paper with significantly higher strength (exception for tear index) and better drainage properties. RKLK yielded the highest paper properties. RKHK gave paper with higher strength properties than BKLK.

Finally, fractionation, due to the possibility of beating the long fiber portion of the pulp more extensively, provides a good opportunity to achieve better fibrillation, enhance fiber bonding, and produce paper with higher strength properties, especially in the case of kenaf high kappa pulp. This can be considered as a new approach to enhance kenaf whole stem pulp properties.

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