SODA-ANTHRAQUINONE PULP FROM MALAYSIAN CULTIVATED KENAF FOR LINERBOARD PRODUCTION

Ahmad Azizi Mossello,[a, d *] Jalaluddin Harun,[a] Hossein Resalati,[b] Rushdan Ibrahim,[c] Paridah Md Tahir,[a] Seyed Rashid Fallah Shamsi,[d] and Ainun Zuriyati Mohamed [a]

The goal of this study was to prepare soda- anthraquinone pulp from kenaf whole stem and to compare the resultant core and bast pulps for linerboard production. Pulping was done under mild cooking conditions (active alkali 12-15%) with a cooking time of 30-90 min and a temperature of 160ºC. During the pulping process, kappa numbers ranged from 56.0 to 20.6, while total yields varied from 58.4 to 54.2% with a rejection rate of 2.3 to 0.1%. Based on the quality of pulp produced, kappa numbers 49.4 and 25.4 was selected as symbolic of high and low pulps respectively. The results of the study revealed significant difference between the properties of core, whole stem (KHK and KLK), and bast pulps. Core pulps with low freeness and high drainage time the study found produced sheets with greater density, tensile index, burst index and RCT, with lower light scattering coefficient and tear index than bast pulp. Whole stem pulps showed properties between those of core and bast pulps. Moreover, KLK with high drainage time produced papers with significantly higher strength properties than KHK.

Keywords: Malaysian cultivated kenaf; Soda-AQ pulp; Whole fiber; Linerboard; Fiber bonding

*Contact information: a: Institute of Tropical Forestry and Forest Products, University Putra Malaysia, Malaysia; b: Faculty of Forestry and Wood Technology , Gorgan University of Agricultural and Natural Resources, Iran; c: Forest Research Institute Malaysia, Malaysia; d : Department of Desert Region Management, College of Agriculture, Shiraz university, Shiraz,Iran; *Corresponding author:aziziahmad99@yahoo.com / azizi1353@gmail.com*

INTRODUCTION

In Malaysia, almost 50% of the total paper consumption comes from packaging papers such as kraft liner. However, there is no local production of kraft pulp, and this implies a high reliance on imports (Koay and Leh 2007). On the other hand, the government has actively encouraged the paper and paper board industry to become self-sufficient and to reduce the import of pulp, paper, and board (Jalaluddin et al. 2009). So, the insufficient supply of fiber for papermaking has necessitated the paper industry to search for alternative fiber sources.

In Malaysia, kenaf was first introduced in the early 1970s. It was recognized as a potential alternative material for the production of panel products such as fiberboard and particle board in the late 1990s under the Seventh Malaysian Master Plan 1996-2000 (Abdul Khalil et al. 2010). Due to its potential commercial value, the government allocated RM 12 million for research and future development of kenaf-based industry in the Ninth Malaysian Plan 2006-2010 (Mohd Edeerrozey et al. 2007). Under the plan, the National Kenaf and Tobacco Board (LTN) engineered the development of kenaf cultivation in order to replace tobacco cultivation, especially in Kelantan. Moreover, the government emphasized diversification and commercialization of downstream of kenaf based industries, including the pulp and paper industry.

Kraft, soda, and soda-AQ processes have been the most frequently used for kenaf pulping (Dutt et al. 2009; Villar et al. 2009; Khristova et al. 2002; Villar et al. 2001; Ohtani et al. 2001; Khristova et al. 1998). In comparison to kraft pulping, soda-AQ process has higher yield at the same kappa level and better delignification (Ohtani et al. 2001) without environmental damage due to the absence of sulphur emissions (Jimenez et al. 2009; Holton 1977). The use of soda-AQ for kenaf whole stem entails the utilization of less chemical, it also ensures higher pulp yield than soda pulping (Khristova et al., 1998). It is equally considered suitable for small scale mills (Jimenez et al. 2009; Palmer et al. 1986).

Some researchers have carried out studies based on locally available kenaf in the production of pulp and paper. Mohd Nor et al. (2004) investigated the potential of kenaf fiber for pulping and papermaking and reported the kenaf fibers obtained from bast, core, and whole plant can be used to produce both mechanical and chemical pulps with good strength properties. Long and slander bast fibers with low lignin content allow this material to be comparable, if not superior, to the softwood fiber for special paper products. Moreover, a small pulp mill can be established and become viable provided that land is available for kenaf cultivation in the production and supply of the fiber material. Sharmiza et al. (2005) studied kraft pulping properties of kenaf fibers and concluded that at the same cooking condition, core fibers were superior in term of tensile strength but weaker in tear and burst strengths when compared against bast fibers at same freeness. The whole stem fibers showed strength values between both core and bast fibers. Ashori (2006), by using the kraft pulping process, showed that bast fibers were relatively easy to cook, resulting in good pulp yields in the range of 45-51%. The bast pulp produced sheets with great density and tear index. Rushdan et al. (2009) produced kenaf whole stem soda-AQ pulp with screened yield 50% and kappa number 13 by optimizing cooking conditions (alkali charge 20%, cooking time 120 min and cooking temperature 160 °C). The goals of this study therefore were to make soda-AQ pulp from kenaf whole stem and compare the resulting pulps to core and bast pulps used in linerboard production.

EXPERIMENTAL

Materials

Kenaf (*Hibiscus canabinus*), variety 36, was planted on February 4 and harvested by Harvester Mover Machine on June 10, 2008 at the National Tobacco Board (LTN), Malaysia. All the raw materials were taken from one harvest, to ensure that, as far as possible, variations in raw materials used were kept to a minimum. The stalks were predominantly 320 cm in height and 1.9 cm in diameter at the base. The stem consisted of 64.51% core and 35.49% bast on an oven-dry weight basis. The raw material used in this study was kenaf whole stem. For comparison, kenaf bast and core were also used. The whole stems were chopped to 2-4 cm length with mini chipper (PALLMAN) and screened to separate fine and over size particles. Also, manually separated kenaf bast and core fibers were cut into 3 cm length by a guillotine cutter. The chips were air dried and kept in bags for the study.

Methods

Pulping and pulp characterization

The soda-AQ pulp of Malaysian cultivated kenaf whole stem due to low lignin content (16.67%), high holocellulose (76.89%), and high alpha- cellulose to lignin ratio (3.18) (Azizi Mossello et al. 2009) was done at mild cooking conditions (low active alkali and cooking time) (Table 1) to reach good yield and satisfactory delignification. Soda-AQ pulping from whole stem was processed in a 6-liter M.K. system mini digester. Pulping temperature, time to cooking temperature, and liquor to raw material ratio were held constant during all the experiments. After cooking, the hot-softened chips were disintegrated by a Bauer disk refiner with 3 mm clearance (Calabro 1992). The disintegrated pulps were washed and screened in a vibratory flat screen device with a slot width of 0.15mm to determine rejects and screened yields. The reported total yield was the sum of reject and screened yield. The kappa number for all the screened pulp samples was determined according TAPPI T 236 om-99. Kappa number was converted to residual lignin content using a multiplying factor of 0.15 (Ren et al. 1996). Based on pulp properties in terms of total yield, screened yield, reject, and kappa number, two pulping conditions were selected; these produced enough pulp for paper characterization. As for comparison, bast and core fiber pulping were carried out at an active alkali (A.A.) level of 15% and a cooking time of 60 min.

Table 1. Soda-AQ Pulping Conditions for Kenaf Whole Fiber

Pulping condition	Values
Active alkali (Na_2O based on o.d. fiber), %	12, 13.5, 15
AQ (based on o.d. fiber), %	0.1
Liquor to raw material ratio	7:1
Time to maximum temperature, min	60
Time at maximum temperature, min	30, 60, 90
Cooking temperature, ºC	160
Raw material weight (oven dried), g	300

Paper characterization

The freeness and standard drainage time of the pulp were determined according to TAPPI T 227 om-99 and T 221 cm-99 respectively. The handsheets with a base weight of 150 g/m^2 were made in a British handsheet former according to TAPPI T 205 sp-02 specification and tested for strength properties (tear index, tensile index, burst index, and RCT) in line with TAPPI T220 sp-01. The light scattering coefficient is the ability of the interior of the test sheet to scatter light (Clark 1985), which involves measuring the reflection of a single sheet backed by a black body (R_0) and measuring the reflection of the same sheet when backed with multiple sheets of the sample (R_∞). In this research, the light scattering coefficient was automatically measured using a Color Touch^{TM} spectrophometer model ISO (Technidyne Corporation) according to C/2ºC illumination observation technique, corresponding to TAPPI T425 om-01. However, the surface structure of the handsheets was observed with a scanning electron microscopy (SEM).

Statistical analysis

The pulping experiment was conducted using a completely randomized design as a full factorial experiment with two factors, active alkali, and cooking time (each factor had three levels). Conversely, the paper properties experiment was done as a completely randomized design with four types of pulp used in the treatments. The variance and Duncan Multiple Range test was conducted to show the difference between the treatments. Statistical procedures were carried out using SPSS and MSTAC software.

RESULTS AND DISCUSSION

Pulping and Pulp Characterization

The results from soda-AQ pulping of kenaf whole stem are given in Table 2. It can be seen that all combinations of these two factors were completely different from each other. By increasing A.A. and cooking time, the kappa number decreased. At a lower level of A.A (12%), kappa numbers were very high. For example, after 30 min of cooking at 12% active alkali (Cooking1) the kappa number was 56.0, which indicated 8.41% residual lignin in pulp. This result can be explained from the abundance of hot water extractives (8.57%) (Azizi Mossello et al. 2009) that consume alkali rapidly during cooking (Ohtani et al. 2001), thereby increasing the alkali charge required for efficient delignification.

Table 2. Soda-AQ Pulping Results for Malaysian Cultivated Kenaf Whole Stem

Pulping variables			Response			
Cooking	**A.A.**	**Time**	**Kappa no.**	**Total yield**	**Reject**	**Screened yield**
	(%)	(min)		(%)	(%)	(%)
1	12	30	56.0a†	58.4a	2.3 a	56.1a
2	12	60	49.4b	58.0ab	1.8 b	56.2a
3	12	90	41.4d	56.7bc	1.1c	55.6ab
4	13.5	30	44.4c	56.7bc	1.1c	55.6ab
5	13.5	60	36.7e	55.9cd	0.6d	55.3abc
6	13.5	90	31.0f	54.7de	0.3de	54.4bc
7	15	30	30.8f	55.5cde	0.5de	55.0abc
8	15	60	25.4g	54.9de	0.2de	54.6bc
9	15	90	20.6h	54.2e	0.1e	54.1c

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

Reject is the fraction of pulp retained the on a screen, which can be a good indicator of the uniformity of the raw material or the inefficiency of chemical treatment (Wanrosli et al. 2004). Table 2 shows reject values of pulps. The result shows that the Cooking 1 condition yielded highest reject content. By increasing A.A. and time, reject content decreased, due to better delignification and separation of fiber bundle. From

Cooking 5 forward, the reject content was less than 0.6%. A reject content less than 1% is indicative of easy and uniform cooking (Wanrosli et al. 2004).

Table 2 shows soda-AQ pulping of kenaf whole stem. It can be seen that total yield and screened yield ranged from 58.4 to 54.2% and 56.1 to 54.1%, respectively. These results can be attributed to high hollocellulose content (76.89%) (Azizi Mossello et al. 2009) and the preservation of the polysaccharides by AQ (Holton 1977). Active alkali and cooking time had minor effect on the total yield and screened yield. Figure 1 shows the total yield and screened yield as a function of kappa number. During cooking, with decreasing kappa number from 56.0 to 20.6 (a reduction of 63.3%), total yield decreased from 58.4 to 54.2% (a reduction of 4.23%) and the screened yield decreased from 56.1 to 54.1% (a reduction 3.60%). This shows selective delignification, which can be explained by the ability of AQ to act as a catalyst during pulping. It restrained polysaccharides against alkaline peeling, as well as improved delignification (Dutt et al. 2009; Kristova et al. 2006; Khristova et al. 2002, Karakus and Roy 1998).

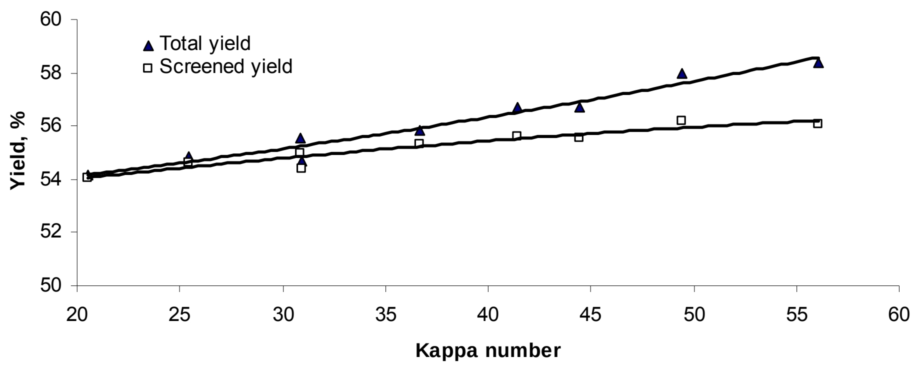

Figure 1. Total and screened yields as function of Kappa number (at different active alkali and cooking time as in Table 2)

According to the results in terms of total yield, rejection level, screened yield, and kappa number (Table 2), Cooking 2 (A.A. 12% and cooking time of 60 min) and Cooking 8 (A.A. 15% and cooking time of 60 min) were selected for paper characterization. Pulps from Cooking 2 with kappa number 49.4 and Cooking 8 with kappa number 25.4 were donated as kenaf high kappa (KHK) and kenaf low kappa (KLK), respectively.

The results of soda-AQ pulping of kenaf bast and core fibers are shown in Table 3. It can be seen that under same cooking conditions, bast fiber produced pulp with significantly higher yield, lower kappa number, and lower rejects than core and whole fibers. Moreover, the whole fiber pulp was intermediate in quality between core and bast (See Table 3). It was expected that bast fiber, due to its high holocellulose (81.66 vs.74.83%) and low lignin contents (11.23 vs. 20.26 %), should be easily pulped and provide high pulp yield (Azizi Mossello et al. 2009). In comparison to kraft pulping (Ashori 2006; Sharmiza et al. 2005; Mohd Nor et al. 2004), soda-AQ pulping produced higher yield at milder cooking condition.

Table 3. Soda-AQ Pulping Result for Malaysian Cultivated Kenaf (core, whole and bast) at A.A. 15% and Cooking Time 60 min

Pulp	Kappa no.	Total yield (%)	Reject (%)	Screened yield (%)
Core	29.5a[†]	51.8c	0.1a	50.9c
Whole	25.4b	54.9b	0.2b	54.6b
Bast	20.2c	56.2a	0.1b	56.2a

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

Paper Characterization

Table 4 shows the properties of handsheets made from unbeaten kenaf core, whole (KHK and KLK), and bast pulps. It can be seen that the properties of core, whole, and bast pulps differed from each other significantly. The primary difference was that core pulp had the lowest freeness and highest drainage time, followed by whole (KHK and KLK) and bast pulps, respectively. The surface area affects freeness as the surface area increases, the freeness decreases(El-Hosseiny and Yan 1980) Core pulp, due to the presence of fine and parenchyma cell with higher surface area (Villar et al. 2009), has lower freeness and higher drainage time. In case of whole stem pulps, the KLK had significantly higher drainage time than KHK, which can be explained as due to low lignin content (3.82% vs.7.42%), which results into higher flexibility of the fibers (Minor et al. 1993) with greater swelling, higher water retention, and slower drainage than KHK.

Table 4. Comparison Hand sheet Properties of unbeaten Kenaf Fraction Pulps

Parameters	Core	KHK	KLK	Bast	CV%[††]
Freeness, CSF	291c[†]	428b	439b	640a	2.42
Drainage time, s	12.52a	7.75c	8.49b	1.89d	3.96
Apparent density, g/cm^3	0.716a	0.590b	0.620b	0.502c	5.18
Light scattering coefficient, m^2/kg	16.85c	24.90b	22.83b	28.43a	8.75
Tear index, mN.m^2/g	5.87d	13.38c	15.11b	20.68a	7.90
Tensile index, N.m/g	83.09a	71.03b	78.84ab	40.83c	11.53
Burst index, kPa.m^2/g	6.09a	4.18c	5.12b	2.66d	11.31
RCT, kN/m	2.87a	1.85c	2.25b	1.43d	8.56

[†] Means within a row followed by different letters differ significantly at α = 0.05
[††] Coefficients of Variation

Apparent density is among the most important properties of paper, since is a good indicator of fiber flexibility and fiber bonding (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). Table 4 shows that core and bast pulps exhibited the highest and lowest density amongst the compared groups. The difference in density can be attributed to the difference in fiber morphology between the two pulps. Core fiber, because of its higher flexibility coefficient (72.33 vs. 58.63) and lower Runkel ratio (0.43 vs. 0.70) (Azizi

Mossello et al. 2009), can easily collapse and make a dense paper (See Fig. 2a), while the bast pulp makes a bulky paper (see Fig. 2d). The whole stem pulps' (KHK and KLK) densities were moderate, between those from core and bast pulps. Moreover, KHK had a lower density when compared with KLK.

The light scattering indirectly indicates unbonded area between the component fibers, thereby providing an inverse estimated degree of bonding (Clark 1985). Bast pulps exhibited the highest light scattering coefficient, followed by the whole pulps (KHK and KLK), and core pulps, respectively. The difference was reflected in the Runkel ratio. Bast pulps, consistent with their high Runkel ratio (0.70) (Azizi Mossello et al. 2009), have tubular and low collapsible fibers that provide a low bonding area (see Fig. 2d). KLK yielded a lower light scattering coefficient than KHK due to the flexibility of the fibers, which was associated with lower lignin content (3.82% vs. 7.42%); this resulted in a higher bonded area (See Fig. 2b and 2c).

Tear resistance is used as an indicator of paper runnability (Nazhad and Sodtivarakul 2004). Tear index depends on fiber length, fiber bonding, and the total number of fibers in the sheet rupture. 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. Moreover, a flexible sheet will distribute the force over a much larger area and, therefore, a larger number of fibers (Institute of Paper Chemistry Staff 1944). From Table 4, differences in the mean values of tear index for bast, whole (KHK and KLK), and core fibers was significantly different. Bast and core exhibited the highest and lowest tear index, which can be explained based on the morphological (principally fiber length) differences of core and bast fibers (Villar et al. 2009). In the case of whole stem, the effective length of fibers from a mixture of bast and core fibers is responsible for tear resistance (Azizi Mossello et al., 2009). The tear index of KLK was significantly higher than that of KHK. This is probably due to better fiber bonding, as indicated by higher paper density and lower light scattering coefficient because KLK has lower lignin content, so its fibers are more flexible, thus increasing the collapsibility and fiber bonding area. Sharmiza et al. (2005) reported the same result for kenaf kraft pulp (19.6, 11.5, and 5.4 mN.m^2/g for bast, whole stem, and core, respectively).

Tensile strength is a very useful property to describe the general strength of paper (Nazhad and Sodtivarakul 2004) and depends on inter-fiber bonding (Setterholm 1979). Bast has significantly lower tensile index than whole (KLK and KHK) and core. Core has higher tensile index than whole (KLK and KHK). Again, differences between the mean values of tensile index for KHK and KLK, and that between KLK and core were not significant at the 95% confidence level (See Table 4). In comparison to kraft pulp (Sharmiza et al. 2005; Mohd Nor et al. 2004), soda-AQ pulp showed almost similar tensile index for core and whole fiber, but a lower value for bast pulp (40.83 vs. 81.1 N.m/g).

Burst strength is an important requirement for linerboard and corrugated container and a good indicator of container resistance to external and internal mechanical stresses (Nazhad and Sodtivarakul 2004). Two factors are responsible for burst strength; these are fiber length and inter-fiber bonding. Increased fiber length ensures higher bursting strength. However, in the view of Brandon (1981), bursting strength is more affected by fiber bonding. Core had the highest burst index and bast had the lowest. KLK, because of its better fiber bonding, had significantly higher burst index than KHK (see Table 4). In comparison to kraft pulps (Sharmiza et al. 2005; Mohd Nor et al. 2004) soda-AQ pulp showed higher burst index for core fiber and lower values for bast fibers.

The stacking strength of corrugated containers can be predicted by measuring the compression strength of linerboard in the cross direction (Karlsson 2006). Compression strength can be estimated by the ring crush test (RCT) (Dahl & Carl 1985). Fibers with better bonding can produce paper with higher ring crush strength (Parker et al. 2005; Worster et al. 1980). The findings in Table 4 show that the means values of RCT for the compared groups were significantly different. The core and the bast showed highest and lowest RCT, respectively. Also, the RCT for KLK was higher than that for KHK due to the difference in the fiber bonding of pulps, as explained earlier. These appear to be the first RCT data to be published for locally produced kenaf.

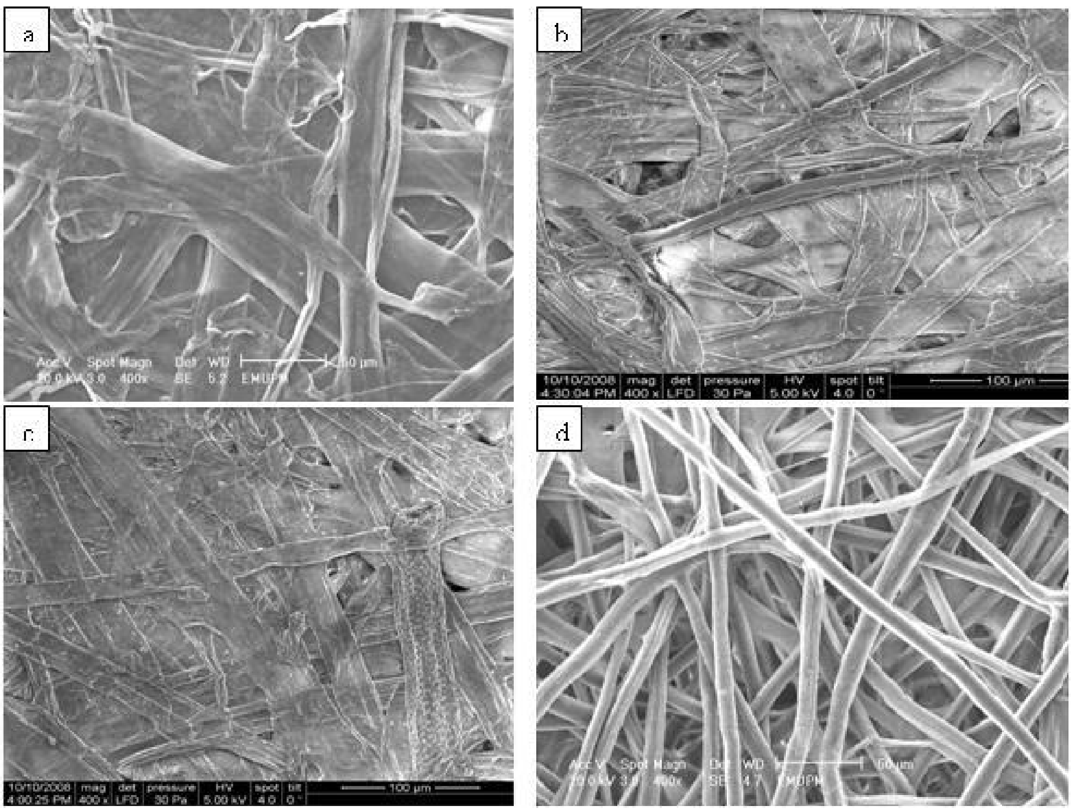

Figure 2. SEM micrographs of unbeaten kenaf fractions soda-AQ pulps with magnification 400x: (a) core, (b) kenaf high kappa number (KHK), (c) kenaf low kappa number (KLK), (d) bast

Table 4. Comparison Hand sheet Properties of Unbeaten Kenaf Fraction Pulps

Parameters	Pulp	Mean	SD	95% Confidence Interval	
				Lower bond	Upper bond
Freeness, CSF	Core	291	10	279	304
	KHK	428	14	411	445
	KLK	439	9	427	450
	Bast	640	9	629	651
Drainage time, s	Core	12.52	0.30	12.15	12.89
	KHK	7.75	0.39	7.28	8.23
	KLK	8.49	0.27	8.15	8.83
	Bast	1.89	0.23	1.60	2.17
Apparent density, g/cm^3	Core	0.716	0.023	0.697	0.735
	KHK	0.590	0.013	0.578	0.599
	KLK	0.620	0.019	0.598	0.633
	Bast	0.502	0.013	0.493	0.512
Light scattering coefficient, m^2/kg	Core	16.85	1.08	15.94	17.75
	KHK	24.90	1.38	23.75	26.05
	KLK	22.83	1.78	21.73	24.64
	Bast	28.43	1.67	26.39	29.93
Tear index, mN.m^2/g	Core	5.87	0.34	5.58	6.15
	KHK	13.38	0.70	12.55	13.67
	KLK	15.11	0.74	14.29	15.70
	Bast	20.68	0.88	18.81	21.52
Tensile index, N.m/g	Core	83.09	3.24	80.38	85.80
	KHK	71.03	3.11	68.42	73.63
	KLK	78.31	2.73	75.78	80.84
	Bast	40.83	3.03	37.40	43.89
Burst index, kPa.m^2/g	Core	6.09	0.18	5.95	6.24
	KHK	4.18	0.12	4.08	4.28
	KLK	5.12	0.23	4.88	5.32
	Bast	2.66	0.35	2.39	2.91
RCT, kN/m	Core	2.87	0.09	2.79	2.94
	KHK	1.85	0.05	1.80	1.89
	KLK	2.25	0.08	2.16	2.32
	Bast	1.43	0.10	1.39	1.50

CONCLUSIONS

1. In conclusion, Malaysian cultivated kenaf whole stem can produce pulp with high total yield (58.4-54.2%) and favorable paper properties (tensile, tear, burst, RCT) under mild cooking conditions (low active alkali and short cooking time) using an environmentally friendly process (soda-AQ). Moreover, by using similar pulping conditions, comparison of kenaf bast, core, and whole stem as separated raw materials have shown that bast was relatively easy to cook, resulting in good pulp yield, while core was more difficult to cook and produced significantly lower yield with higher kappa number. However, whole stem revealed intermediate properties.
2. Kenaf core pulps showed high bonding ability, as indicated by high density and low light scattering coefficient, which produced papers with higher strength

properties, except in the case of tear index when compared to bast pulps. Although bast pulp showed lower properties, it has the potential to be beaten, which improves its strength properties due to its high freeness (640 mL) and low drainage time (1.89s). Moreover, core pulp due to low freeness (291 mL) and higher drainage time (12.52s), is better suited to be used in its unrefined state.

3. In comparison to kraft pulping, soda-AQ gave higher yield at a milder cooking condition with comparable, if not superior, properties to core and whole fiber, especially for burst index, but lower properties for bast fiber, except for tear index, without environmental issues.
4. Based on the findings of this study, soda-AQ pulping of whole kenaf stem was judged to be more suitable for commercialization of kenaf for linerboard production in Malaysia, in comparison to separating core and bast prior to pulping. The process showed good yield and strength properties (especially RCT and burst, which are very important requirements for linerboard), as well as the avoidance of the extra processing steps in separation and the extra cost of two pulping lines,

ACKNOWLEDGMENT

The authors wish to thank the Economic Planning Unit of the Prime Minister's Department Malaysia for the financial support used in conducting this research.

REFERENCES

Abdul Khalil, H., Yusra, A., Bhat, A., and Jawaid, M. (2010). "Cell wall ultrastructure, anatomy, lignin distribution, and chemical composition of Malaysian cultivated kenaf fiber," *Industrial Crops & Products* 31(1), 113-121.

Ashori, A. (2006). "Pulp and paper from kenaf bast fibers," *Fibers Polymer*, 7, 26-29.

Azizi Mossello, A., Ainun, Z. M. A., and Rushdan, I. (2009). "Chemical, morphological, and technological properties of Malaysian cultivated kenaf (*Hibiscus cannabinus* L.) fibers," In M. T. Paridah, C. A. Luqman and K. Norfaryanti (Eds.), *Kenaf Biocomposites, Derivatives & Economics.* Bandar Baru Seri Petaling, Kuala Lumpur: Pustaka Prinsip Sdn. Bhd.

Brandon, C. E. (1981). *Properties of Paper*. In J. P. Casey (Ed.), *Pulp-Chemistry and Technology (3 ed. Vol. III)* New York, USA: John Wiley and Sons.

Calabro, G. (1992). "Kenaf pulp properties as a function of their composition. Yield and freeness," Paper presented at the Pulping Conference, 1-5 November. Boston MA, Book 2, TAPPI Press, Atlanta.

Clark, J. A. (1985). *Pulp Technology and Treatment for Paper*, Miller-Freeman, San Fransico.

Dahl, J., and Carl, B. (1985). "Limited range of the ring crush test," *TAPPI Journal* 68(10), 108-109.

Dutt, D., Upadhyay, J. S., Singh, B., and Tyagi, C. H. (2009). "Studies on *Hibiscus cannabinus* and *Hibiscus sabdariffa* as an alternative pulp blend for softwood: An optimization of kraft delignification process," *Industrial Crops & Products* 29(1), 16-26.

El-Hosseiny, F., and Yan, J. F. (1980). "Analysis of Canadian standard freeness-2. paractical implications," *Pulp and Paper Canada, 81*(6), 67-70.

Holton, H. (1977). "Soda additive softwood pulping: A major new process," *Pulp Paper Canada* 78*,* 1-4.

Institute of Paper Chemistry Staff. (1944). "Instrumentation studies. XLVI. Tearing strenght of paper," *Paper Trade Journal* 118(5), 13-18.

Jalaluddin, H., Feng, Y. L., and Noor Intan, S. A. (2009). "Marketing kenaf in Malasia," Paper presented at the International Conference on Kenaf and Allied Fiber (ICKAF 2009), Kuala Lumpur.

Jiménez, L., Serrano, L., Rodríguez, A., and Sánchez, R. (2009). "Soda-anthraquinone pulping of palm oil empty fruit bunches and beating of the resulting pulp," *Bioresource technology* 100(3), 1262-1267.

Karakus, S., and Roy, D. N. (1998, 25-29 October). "Physical, chemical, soda pulping and papermaking properties of Kenaf as a function of growth," Paper presented at the Technical Association of the Pulp and Paper Industry, Quebec, Canada.

Karlsson, H. (2006). *Fibre Guide–Fibre Analysis and Process Applications in the Pulp and Paper Industry*, Lorentzen, A.B & Wettre, E .T, Sweden.

Khristova, P., Bentcheva, S., & Karar, I. (1998). "Soda-AQ pulp blends from kenaf and sun flower stalks," *BioResource Technology* 66(2), 99-103.

Khristova, P., Kordsachia, O., Patt, R., and Dafaalla, S. (2006). "Alkaline pulping of some eucalypts from Sudan," *BioResource Technology* 97(4), 535-544.

Khristova, P., Kordsachia, O., Patt, R., Khider, T., and Karrar, I. (2002). "Alkaline pulping with additives of kenaf from Sudan," *Industrial Crops & Products* 15(3), 229-235.

Kline, J. E. (1982). *Paper and Paperboard Manufacturing and Converting Fundementals*. San Francisco, USA: Miller Freeman

Koay, W. C., and Leh, C. P. (2007). "Production of environmentally friendly semichemical pulp from oil palm's empty fruit bunches," Paper presented at the Seminar on advances in pulp paper technology Kuala Lumpur.

Minor, J. L., Tim Scott, C., and Rajai, H. A. (1993). "Restoring bonding strength to recycled fibers," Paper presented at the Recycling Symposium, February 28- March 1-4; New Orleans, LA, Atlanta.

Mohd Edeerozey, A. M., Akil., H. M., Azhar, A. B., and Zainal Ariffin, M. I. (2007). "Chemical modification of kenaf fibers," *Materials Letters* 61*,* 2023-2025.

Mohd Nor, M. Y., Sharmiza, A., Latifah, J., and Mahmudin, S. (2004). "Kenaf and the prospects of cultivation for the pulp and paper industries," Paper presented at the Third technical review meeting on the national kenaf research project (25-26, May), Kota Bharu, Kelantan.

Nazhad, M. M., and Sodtivarakul, S. (2004). "OCC pulp fractionation - A comparative study of fractionated and unfractionated stock," *TAPPI Journal* 3(1), 34-50.

Ohtani, Y., Mazumder, B. B., and Sameshima, K. (2001). "Influence of the chemical composition of kenaf bast and core on the alkaline pulping response," *Journal of Wood Science* 47(1), 30-35.

Palmer, E. R., Gibbs, J. A., Ganguli, S., and Gutta, A. P. (1986). "Pulping characteristics of Eucalyptus species grown in Malawi," Report of the Tropical Development and Research Institute, No. 33, London.

Parker, I. H., Conn, A., and Jackson, T. (2005). "The effect of network variables on the ring crush strength of handsheets," *Appita Journal* 58(6), 448-454.

Ren, W., Du, H., Zhang, M., and Ni, Y. (1996). "Characterization of Chinese kenaf bark fibers for production of bleached chemical pulp," *IPPTA* 8(2), 1-7.

Rushdan, I., Nurul Husna, M. H., Latifa, J., Mahmudin, S., & Mohd Nor, M. Y., et al. (2009). "The effect of soda-AQ pulping paremeters on pulp properties of kenaf," Paper presented at the Paper presented at the International Conference on Kenaf and Allied Fiber (ICKAF 2009), Kuala Lumpur.

Setterholm, V. C. (1979). "Overview of press drying," *TAPPI 62* (3), 45-46.

Sharmiza, A., Latifa, J., Mahmudin, S., and Mohd Nor, M. Y. (2005). "Suitability of locally planted kenaf for pulp and paper applications," *Procedings of 3th USM-JIRCAS International Symposium.* JIRCAS (eds. Tanaka R. and Cheng, L.H.) Tsukuba, pp.54-57.

Villar, J. C., Poveda, P., and Tagle, J. L. (2001). "Comparative study of kenaf varieties and growing conditions and their effect on kraft pulp quality," *Wood Science and Technology* 34(6), 543-552.

Villar, J. C., Revilla, E., Gómez, N., Carbajo, J. M., and Simón, J. L. (2009). "Improving the use of kenaf for kraft pulping by using mixtures of bast and core fibers," *Industrial Crops & Products* 29(2-3), 301-307

Wanrosli, W. D., Zainuddin, Z., & Lee, L. K. (2004). "Influence of pulping variables on the properties of *Elaeis guineensis* soda pulp as evaluated by response surface methodology," *Wood Science and Technology* 38(3), 191-205.

Worster, H. E., Bartels, M. E., and Horng, A. J. (1980). "Effect of some kraft black liquor compnents of poorly washed pulp on linerboard properties," *TAPPI* 63(11), 63-65 62.

Article submitted: April 1, 2010; Peer review completed: May 1, 2010; First revision received: May 8, 2010; Second revised version received, accepted, and published: June 2, 2010.