COMPARATIVE PROPERTIES OF SODA PULPS FROM STALK, BAST, AND CORE OF MALAYSIAN GROWN KENAF

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Soda pulping was performed using kenaf stalk, core, and bast as raw materials. It was observed that all these components could yield good paper characteristics when the resulting pulps were beaten to a freeness of 200 to 300 mL. Soda pulp made from the stalk was comparable to the frond from oil palm in sheet properties, but the latter would require higher beating energy to reach similar freeness as compared to the former.

Keywords: Kenaf; Empty fruit bunch; Frond; Soda pulping; Paper properties

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INTRODUCTION

Kenaf (*Hibiscus cannabinus L.*) is a fast growing tropical and subtropical plant of the mallow family *Malvaceae*. It grows wild in Africa, where it is known as guinea hemp. It is cultivated on the Indian subcontinent, where it has been called mesta or ambari since prehistoric times (Anon 1995). India, Thailand, and China are the leading producers of kenaf bast, a jute substitute. Cultivation of kenaf was encouraged in Cuba, Australia, and the United States after World War II, when there was a shortage in supply of jute. Kenaf is used mainly for cordage, canvas, and sacking, but interest has grown in using it to make paper products such as newsprint and linerboard (Ren et al. 1996; Wang et al. 1996; Hou et al. 1996; Taylor et al. 1997; Mohta et al. 1997; Nomura and Takada 1999;) due to growing environmental concerns and increasing global demand for paper and paper products.

Recently, the Malaysian government has been promoting the planting of kenaf for social-economic reasons. Under the ASEAN Free Trade Agreement (AFTA), which came into effect in January 2010, tobacco manufacturers from ASEAN countries can reduce their purchasing quota from Malaysia and source better quality tobacco leaves at lower prices from neighboring countries. As a consequence, the price of tobacco leaves has dropped and the import duties reduced, negatively impacting the competitiveness of Malaysian tobacco farmers. To counteract such an undesirable impact on the life of tobacco farmers, the National Board of Kenaf and Tobacco of Malaysia offers incentives and funding to encourage the tobacco farmers to convert their tobacco schemes to kenaf farming, which has great economic potential (Hanim Adnan 2010). Under the 9th Malaysian Plan (2006-2010), the Malaysian government allocated RM35 million for this program. So far, the government has helped 270 smallholders to establish 700 hectares of kenaf plantations in Kelantan, Terengganu, Kedah, and Perlis (Ching 2010). The objective of the Malaysian National Kenaf and Tobacco Board is to develop the kenaf industry as the country's new source of growth, in conjunction with the palm oil and rubber industries. Realizing the diverse possibilities of commercially exploitable derived products from kenaf, a National Kenaf Research and Development Program has been formed in an effort to develop kenaf as a possible new industrial crop for Malaysia.

The kenaf plant was initially introduced in Malaysia as a high-protein animal feed in recent years (Hanim Adnan 2010). It also has the potential to provide more valuable by-products like textile, construction material, paper, fibreboard, and automotive components if more systematic research and development are undertaken. In fact, some research works have already been conducted on kenaf grown under Malaysian conditions. For instance, Abdul Khalil et al. (2010) studied the anatomical and chemical nature of Malaysian cultivated kenaf fibre, and, based on their findings, they concluded that the Malaysian kenaf is suitable for making panel, pulp, and paper. The chemical and morphological natures of kenaf (variety Everglades 71), grown in Serdang, Selangor were examined by Ashori et al. (2006). In addition, Azizi Mossello et al. (2010) used soda-anthraquinone pulping to evaluate the suitability of Malaysian kenaf for linerboard production and observed that the whole kenaf stalk can be transformed into useful fibres for linerboard production. To better understand the pulping characteristics of Malaysian cultivated kenaf, pulping trials using a soda process were used to investigate the pulping behavior of the whole stalk, kenaf bast, and kenaf core. This fundamental information would be useful for optimizing the chemical transformation of this nonwoody material into papermaking furnish. In addition, TCF and ECF bleaching of kenaf kraft pulp have also been explored (Ashori et al. 2004, 2005).

EXPERIMENTAL

Raw Materials

Air-dry sample of kenaf (sp.V36) was obtained from Nibong Tebal Paper Mill, in Penang, Malaysia, where the average temperature is about 31 °C with a relative humidity of 70 to 90%. It was harvested from a 5-month old plantation. For chemical analyses and pulping trials the stalk was separated manually into bast and core fractions. Each component, including the stalk, was cut 2 to 3 cm in length; the stalk and core were split into 3 to 4 strips in the longitudinal, axial direction to facilitate chemical cooking. The samples used for chemical analyses were grounded into fine particles according to TAPPI T 257.

Chemical Analysis

Kenaf specimens (stalk, bast, and core) were analyzed for lignin, holocellulose, α-cellulose, ash, and extractives (ethanol-toluene). Tests were performed following TAPPI standard methods, except holocellulose which was determined using the technique described by Wise et al. (1946). Fibre length of pulp fibres was measured using a FAS 3000 Fiber Analyzer made by Sherwood Instruments Inc., USA.

Pulping

Soda pulping (stalk, bast, and core) was carried out in a 4-L stationary stainless steel digester (NAC Autoclave Co. Ltd., Japan) fitted with a computer-controlled thermocouple. The following conditions were employed based on previous work (Wan rosli et al. 1998, 2004): liquor-to-material ratio of 8:1, time to maximum temperature of 90 min, maximum temperature of 170 °C, cooking time at maximum temperature of 120 min, and NaOH charge (w/w based on oven dried fiber) of 15, 20, 25, and 30%. These conditions produced pulps with yields ranging between 40 and 50%. The Kappa number was determined following the TAPPI method T 236. For comparison purposes, cooking of fibrous strands of oil palm empty fruit bunch (EFB) and fronds were also conducted using 25% alkali charge, other conditions being kept unchanged. At the completion of the cook, the pulps were mechanically disintegrated in a three-bladed mixer for 1 min at 2% consistency. Next, each pulp was screened on a flat-plate screen with 0.15 mm slits and stored in plastic bags for further use.

Beating

The experimental pulps were beaten in a PFI mill, at 10% consistency, in accordance with TAPPI T 248. The number of revolutions applied varied from 250 to 1500. The resulting freeness ranged from about 250 to 600 mL. Latency of the beaten samples was removed by shear-disintegration in hot water (≈ 95 °C) by means of a laboratory disintegrator before standard handsheets were formed.

Handsheet Formation and Testing

Standard handsheets of 60 g/m^2 were prepared from various specimens. The sheets were conditioned at 23 °C and 50% RH for at least 24 h before testing, according to appropriate TAPPI standard methods.

RESULTS AND DISCUSSION

The average fibre length of bast and core fibres were, respectively, 1.94 and 0.7 mm, which are comparable to those previously reported (Ashori et al. 2006; Azizi Mossello et al. 2010) where a Quantimer Image Analyzer was used for measuring fibre length (Azizi Mossello et al. 2010). On the other hand, Abdul Khalil et al. (2010), who used the same material source, gave much higher values in fibre length, i.e. 3.64 mm for bast and 1.10 mm for core. Apparently, the difference might be attributed to the techniques used, for example, instruments and preparative procedures. The technique used for separating the fibres (e.g. maceration) in the case of Abdul Khalil et al. (2010) was not clear. Incomplete fibre separation could lead to greater values in fibre length. In addition, material sampling might also partially responsible such discrepancy, since fibre length could vary widely from bottom to top of the plant (usually the fibres at the top are shorter than those in lower portion of the stem). In this study a FAS 3000 Fiber Analyzer was used while a DIMAS Expert Software was employed in Abdul Khalil et al. (2010). According to Abdul Khalil et al. (2010) and Ashori et al. (2006), the core fibres had a larger diameter than the bast counterpart, 6.7 µm vs. 2.8 µm, and the latter had a thicker

S2 layer, 1.5-2.5 μm as compared to 0.3 to 1.6 μm. Ashori et al. (2006) also observed that the bast fibres had a thicker cell wall (4.85 μm) than the core counterpart (4.08 μm). These differences in fibre dimension between the bast and core fractions could have a significant influence on paper properties.

The proximate chemical composition of Malaysian cultivated kenaf is presented in Table 1. Note that the bast had higher holocellulose and α-cellulose than the core counterpart did, but it had lower lignin, ash, and extractives contents. The chemical composition found in this work was comparable to those published in Abdul Khalil et al. (2010) and Ashori et al. (2006), considering the natural variations in chemical characteristics of raw materials. Based on the fact that the bast fraction had longer fibres and higher holocellulose and α-cellulose combined with low lignin content, it could be easier to pulp and might result in better mechanical properties of the paper. Further, the lower lignin content coupled with lower extractives of the bast would facilitate its pulping and produce pulp at higher yield and lower Kappa number (Table 2) when compared to the core counterpart. As a result, this would also improve its bleachability.

Table 1. Proximate Chemical Composition of Malaysian Cultivated Kenaf

Sample Type	Holocellulose (%)	α-cellulose (%)	Lignin (%)	Ash (%)	Ethanol-Toluene (%)
Stalk	78.3	52.1	20.3	4.2	3.3
Bast	86.4	57.5	13.7	3.3	2.9
Core	83.2	47.4	20.7	4.7	4.7

Sodium hydroxide is known to be a powerful swelling agent for lignocellulosic materials such as wood and nonwood plant materials. Its swelling ability is particularly evident for materials that have low lignin content, for example hardwood (deciduous species) and nonwood plants (e.g. wheat straw, switchgrass, kenaf, bagasseh, and corn stalk, etc.). The efficiency of soda pulping of kenaf is, therefore, dependent on the alkali charge used; high alkali charges would have more swelling and dissolving capabilities as compared to low alkali charges. For a given set of pulping conditions, the Kappa number (a measure of lignin content) decreased with increasing alkali charge (Table 2). Since the kenaf bast had higher hollocellulose and α-cellulose and lower lignin content as compared to the kenaf core (Table 1), it consistently resulted in lower Kappa number vis-à-vis the core counterpart (Table 2). Low Kappa number or lignin content would make the pulp easier to beat and render the fibres more flexible and conformable in sheet consolidation, yielding increased fibre bonding. Note that when the alkali charge was relatively low (15 and 20%) the stalk yielded the highest Kappa number, which might be due to slow reactive penetration into the stalk where the core was enveloped by the bast layer containing an epidermis on the surface. This epidermis (protective layer) might hinder somewhat the penetration of pulping liquor. However, as the alkali load was augmented to 25 and 30%, these higher concentrations overcame the penetration barrier (e.g. dissolution of epidermis), resulting in lower Kappa number compared to the core fraction. In fact, the alkali would react in advance with the bast on the stalk prior to reaching the core. It is, thus, suggested that the stalk be mechanically crushed to a certain degree to facilitate the penetration of pulping liquor.

Table 2. Kappa Numbers of Malaysian Cultivated Kenaf at Various Alkali Charges

Alkali charge (%)	15	20	25	30
Stalk	28.1	25.8	14.5	10.2
Core	19.3	18.2	16.5	13.8
Bast	18.3	14.9	10.3	8.5

Due to the shortness of its fibrous elements, the core fraction exhibited noticeably lower freeness (Fig. 1A) in contrast to the bast counterpart, which had much longer fibres as discussed earlier. The short fibres of the core render the fibrous pad denser, resulting in reduced drainage rate or low freeness. The long elements of the bast formed a more porous fibrous pad during the filtration process, decreasing the drainage time or increasing the freeness. Regarding the whole kenaf stalk, it showed intermediate characteristics since it is composed of 60 to 75% core fibres and 25 to 40% of bast fibres, on dry weight basis (Abdul Khalil et al. 2010).

The effect of alkali charge on the apparent sheet density could not be clearly defined when the pulps of each kenaf fraction were beaten to the same level of freeness (Fig. 1B). However, at a given freeness, the short core pulp fibres made denser sheets when compared to the longer bast counterparts, while the stalk produced sheets with density between the other two fractions.

At high freeness the fibres were not sufficiently fibrillated; therefore, the short core fibres could not compete with the bast fibres, which had much longer length and yielded higher tensile strength. However, at lower freeness (e.g. less than 300 mL) the fibres were relatively well refined and fibrillated. As a result, the difference in tensile index between the core and the bast narrowed and diminished, meaning that the effect of fibre length was overridden by the increase in fibre bonding capabilties of fibres. Note that the stalk gave excellent tensile strength (about 70 to 80 N.m/g when freeness was 300 mL or less) due to the presence of both short (e.g vessels and parenchyma cells) and fibrous (e.g. vascular fines) elements. These values were comparable to those reported for soda-AQ kenaf pulp at similar freeness, e.g. 72 N.m/g for bast and 83 N.m/g for core (Ahmad Mossello Azizi et al. 2010). Law et al. (2003) used alkali-sulphite to produce high-yield (60 to 80%) pulps from American kenaf and obtained excellent tensile (50 to 60 N.m/g) and tear (12 to 13 mN.m^2/g) for the bast fraction in freeness range of 200 to 300 mL. Much lower properties were observed for the core fraction. Considering production cost and strength properties, it would be desirable not to separate the bast from the core fraction in pulping.

The characteristics of bursting strength development (Fig. 2B) were similar to that observed for tensile index (Fig. 2A); these two properties are normally directly correlated to each other, because the main factor affecting these two properties is inter-bonding potential of individual fibres that make up the sheet structure. In a freeness range of 200 to 300 mL, the three types of pulps had a comparable burst index, about 8 to 9 kPa.m^2/g, which is remarkably better than those reported by Ahmad Mossello Azizi et al. (2010) for similar freeness.

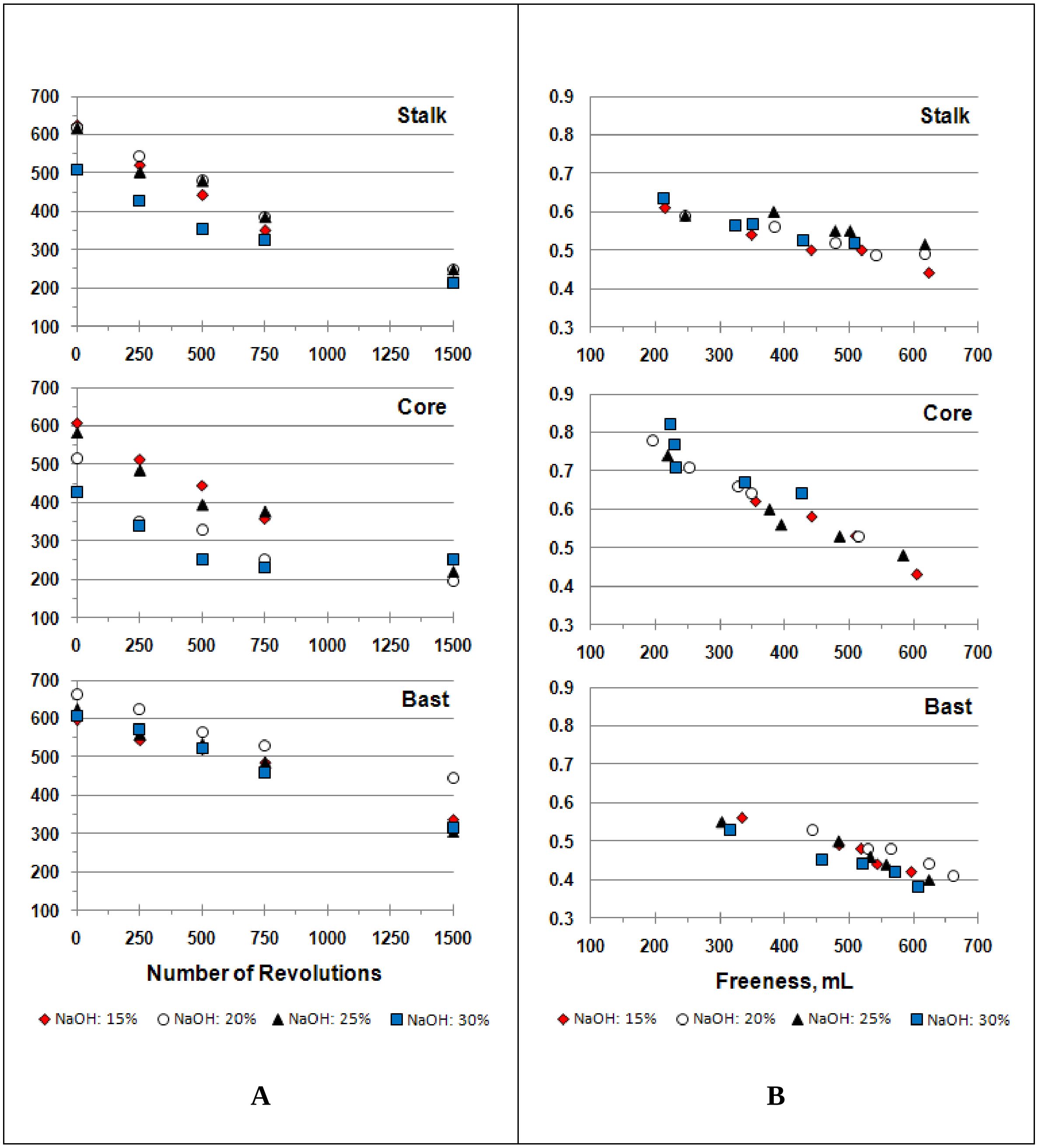

Fig. 1. Freeness (y-axis, mL) as a function of number of revolutions (A) and apparent density (y-axis, g/cm^3) as a function of freeness (B)

In terms of tensile index, the difference between the core and bast was dependent on the freeness levels. At freeness higher than 300 mL (approximately) the core pulps were clearly inferior to those of the bast (Fig. 2A).

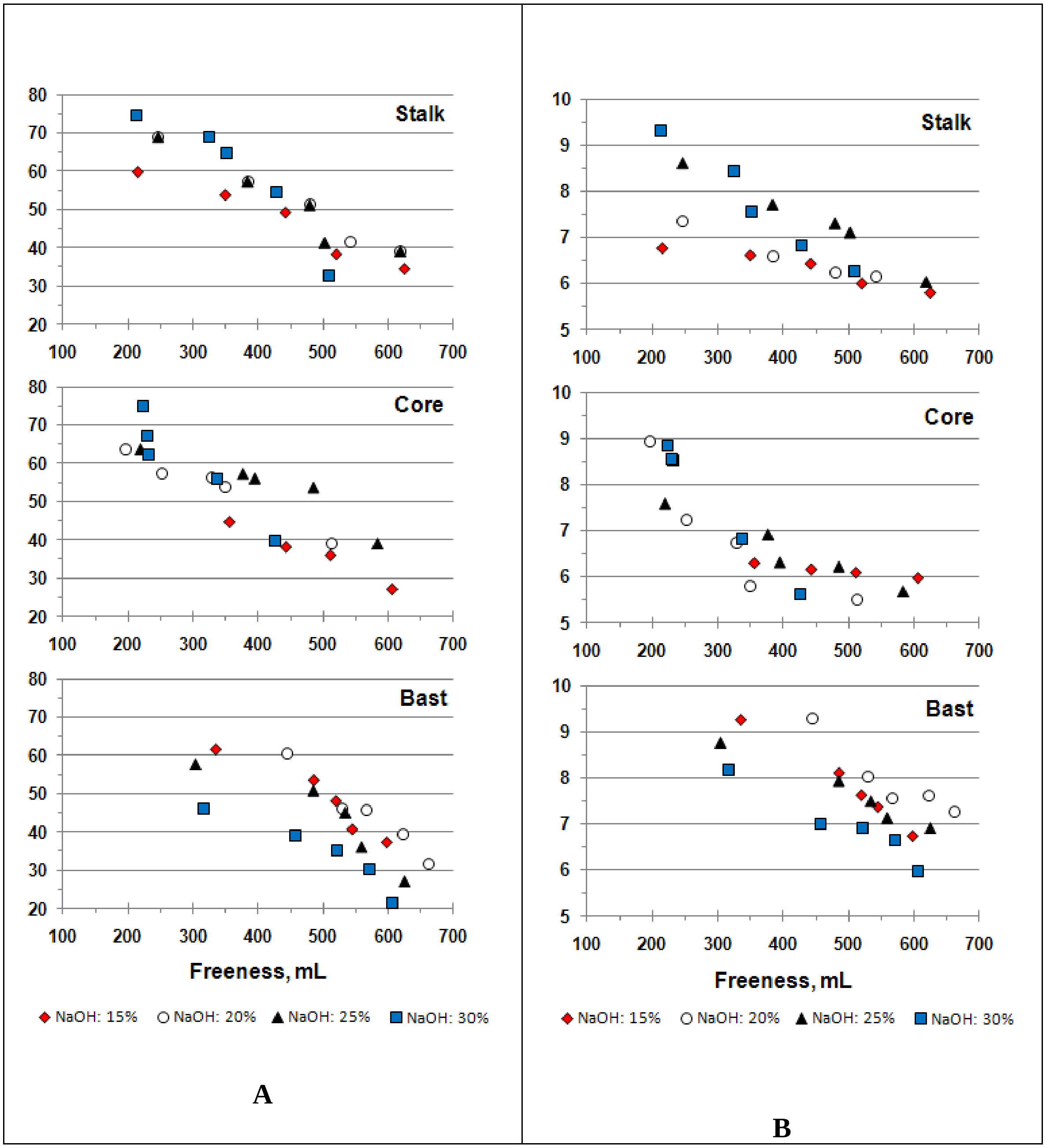

Fig. 2. Tensile index (y-axis, N.m/g) as a function of freeness (A) and burst index (y-axis, kPa.m^2/g) as a function of freeness (B)

As in the cases of tensile and burst indices, the influence of alkali charge on tear index could not be clearly defined when the pulps were beaten to a given freeness (Fig. 3). However, in the useful range of freeness between 200 and 300 mL, good tear indices could be obtained from the three kinds of pulps, e.g. stalk had 8 to 10, core 6 to 7, and bast 14 to 15 mN.m^2/g. Since the bast had long fibres, it showed the best tear index. However, the stalk appeared to be the best compromise.

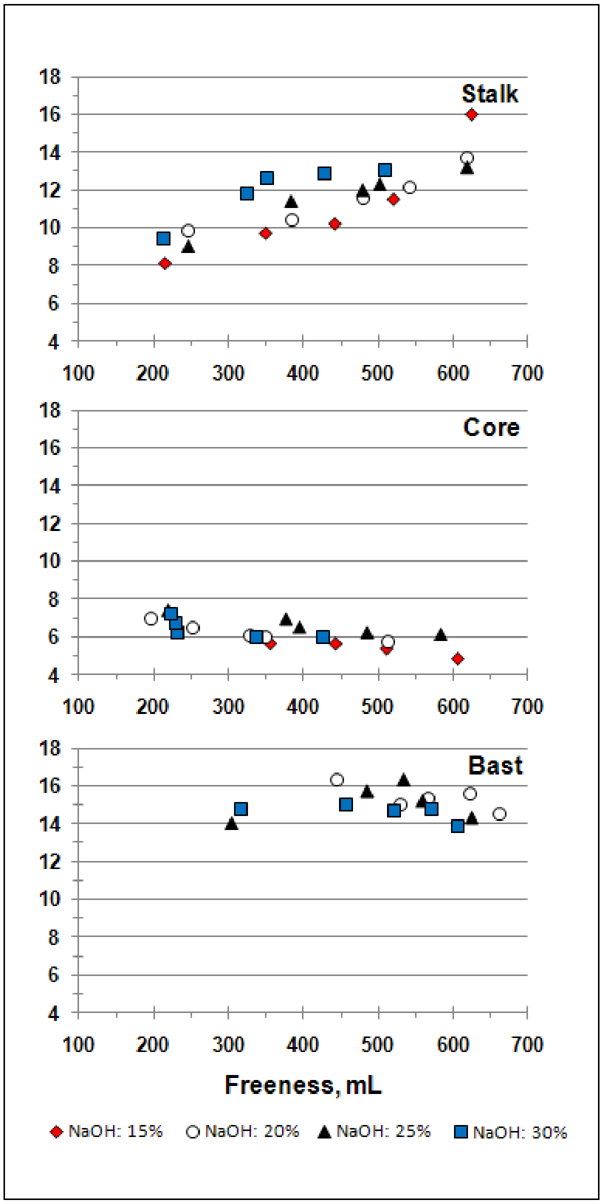

Fig. 3. Tear index (y-axis, mN.m^2/g) as a function of freeness

Figure 4 compares three major properties of kenaf stalk with empty fruit bunch (EFB) and frond from oil palm. The pulps were prepared using a soda process with identical cooking conditions as described in the experimental section and beaten in a PFI mill up to 3500 revolutions.

As seen in Fig. 4A, the oil palm fibres, particularly the frond, required much more beating energy to reach a given freeness as opposed to the pulp prepared from the kenaf stalk. This observation might be partially accounted for by the difference in Kappa number between the pulps. Under identical pulping conditions, the oil palm fibres showed higher Kappa numbers; especially the frond, whose Kappa number was 39.8, whilst EFB and kenaf stalk were measured at 23.5 and 15.4, respectively. However, the role of fibre morphology could not totally be ruled out. Future studies should examine this aspect.

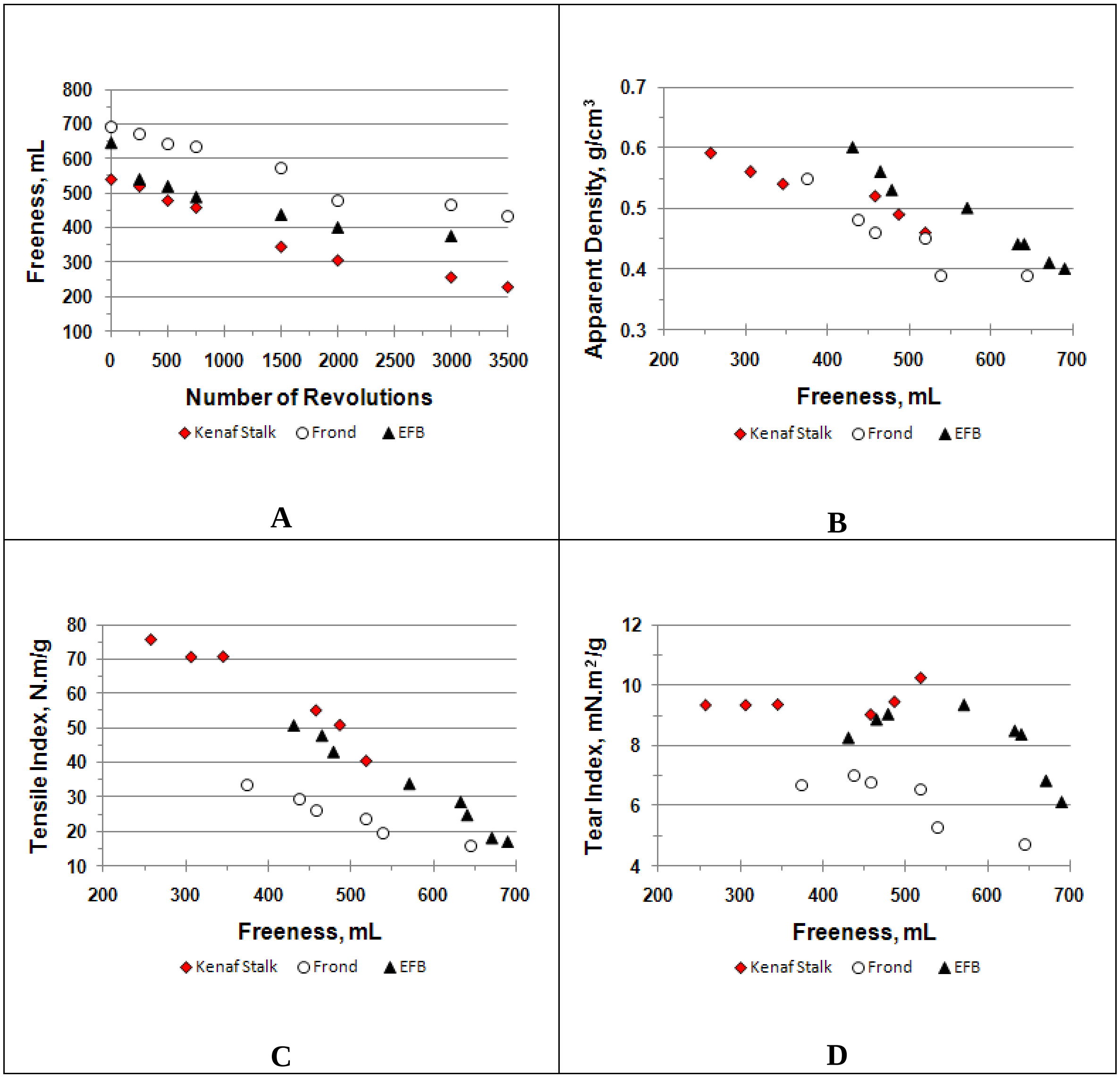

Fig. 4. Comparision of kenaf stalk with empty-fruit-bunch (EFB) and frond of oil palm. A: beating revolution; B: apparent density; C: tensile index; D: tear index.

Within the limit of beating revolutions (max. 3500 rev.) the oil palm fibres could not be developed into low freeness pulp as compared to the kenaf stalk fibres (Fig. 4B). The EFB fibres produced sheets with lower density when the freeness was above 300 mL (approximately), as compared to the kenaf stalk and frond counterparts. By extrapolation of the beating curves, it was not unreasonable to state that the oil palm pulps could be developed with more beating energy to yield handsheet density similar to that of the paper made with kenaf stalk fibres, at a given freeness.

Generally speaking, the EFB had the lowest tensile strength (Fig. 4C) and tearing resistance (Fig. 4D) in comparison with the kenaf stalk and frond fibres, at a given freeness. On the other hand, for freeness greater than 300 mL, the kenaf stalk and frond fibres had comparable sheet properties. However, the frond fibres were more resistant to the mechanical treatment in a PFI mill, which produced pulps with high freeness within the limit of beating revolutions used in this study. If this frond pulp had been further treated with greater beating energy, this pulp would, by extrapolation of the beating curve, have yielded properties comparable to those of the kenaf stalk obtained at freeness lower than 300 mL.

Further, it was noted from Fig. 4A that the EFB pulp also required higher beating energy when compared to the kenaf stalk counterpart, resulting in higher freeness at a given number of beating revolutions. However, speculatively, the EFB pulp would not be able to compare with the kenaf stalk pulp in mechanical properties even if it consumed additional beating energy, due to its short fibrous elements.

CONCLUSIONS

In general, the impact of alkali charge on the nature of sheet property development of kenaf stalk, core, and bast fractions cannot be clearly distinguished when the properties are expressed as a function of freeness. This means that for a particular kenaf fraction, the effect of alkali charge is not clearly evident when the pulps are beaten to similar freeness levels, regardless of the differences in Kappa number among the pulps. It also indicates that the influence of Kappa number is overshadowed by the effect of mechanical beating, which generates fibre surface fibrillation.

All three principal kenaf fractions, stalk, core, and bast, can produce soda pulps with excellent sheet properties when the pulps are beaten to freeness of 200 to 300 mL. It is, however, recommended that the kenaf stalk be employed in pulping when considering production cost and paper properties.

Soda pulp of kenaf stalk possesses similar sheet properties vis-à-vis the soda pulp of oil palm frond, at comparable freeness; it is superior to the empty fruit bunch of oil palm in papermaking characteristics.

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