PULPING PROPERTIES OF KRAFT PULP OF NIGERIAN-GROWN KENAF (*HIBISCUS CANNABINUS* L.)

Jacob Smith Udohitinah [a] and Abiodun Oluwafemi Oluwadare [b,*]

This study was centered on finding a locally sourced alternative to imported long-fibre pulp for Nigerian pulp and paper mills. Fibre characteristics, chemical composition, and paper properties of pulp handsheets at different levels of kappa number and freeness in the range of 10 ^{o}SR and 62 ^{o}SR were evaluated using air-dried bast fibre obtained from decorticated kenaf plants grown in southern guinea savanna near Jebba, Nigeria. Kenaf bast fibre compared well with softwood, with an average fibre length of 2.90 mm, a flexibility ratio of 57%, and a Runkel ratio of 0.76. Ash, lignin, and pentosan contents were 0.6%, 12.5%, and 10.6%, respectively, while the cellulose content was 55.5%. Under alkali charge of 15.0 and, sulphidity of 17.5 with constant temperature, cooking time, and liquor-to-fibre ratio of 4.5:1, the screen yield was between 48.8 to 52.8 % with kappa number 12.04 to 20.5. Unbleached pulpsheets at kappa number between 15 and18.5 and pulp freeness 55 ^{o}SR and bleached pulp freeness between 148 and 336 mLs had better quality paper in terms of overall pulpsheet strength properties.

Keywords: Fibre characteristics; Chemical composition; Kraft Pulp; Screened yield; Pulp sheet properties; Hibiscus cannabinus

*Contact information: a: Department of Chemical Engineering, Covenant University, Ota, Ogun State, Nigeria.; b: Department of Forest Resources Management, University of Ibadan, Box 9054, U.I. Post Office, Ibadan, Nigeria, Post code 200005*Corresponding author: femioluwadare@yahoo.com*

INTRODUCTION

Activities of the paper, pulp, and board sub-sectors have long been regarded as main indicators of economic development of a country. The per capita paper consumption growth curves follow the general movement with gross national products, gross domestic product, and growth in literacy level of a nation (Diessen 1998). In line with the unique position of paper and pulp to the economic well being of a country, the federal government of Nigeria established three major paper mills namely; Nigerian Paper mills Limited, Jebba, Kwara State, Nigerian Newsprint Manufacturing Company, Oku-Iboku, Akwa-Ibom State, and Nigerian National Paper Manufacturing Company, Iwopin, Ogun State with total rated capacity of 265,000 metric tonnes (Osadare 1995). The original idea was to achieve self sufficiency in local demand for paper and paper products and to make Nigeria an exporter of pulp and paper products to the neighbouring countries. Given the unique ecological location of Nigeria with vast forest resources, the mills were designed to utilize mixtures of short fibre-hardwood species and imported long fibre pulp. While the short fibre pulp woods are found at the various ecological zones of Nigeria (Adeogun and Sotannde 2007), the huge investment on imported long fibre pulp has been a militating factor against the growth of the pulp and paper industry in the country (Osadare 1995; Aruofor 2000).

The climatic restriction to the establishment of sufficient long fibre pulpwood in Nigeria and the huge investment for importation of long fibre pulp has prompted researchers to explore whether fibres from non-wood species could be used for papermaking. Among the various non-woody plants that thrive well in Nigeria, *Hibiscus cannabinus*, commonly called kenaf, stands prominent.

Kenaf (*Hibiscus cannabinus* L.) is an annual crop in the family of *Malvaceae* that has been identified as a viable replacement for trees in the pulp and papermaking process. While the cultivation of kenaf is still in its infancy stage in Sub-Saharan Africa, kenaf is attracting much interest because of its apparent environmental and economic benefits (Nkaa *et al*. 2007; Balogun *et al*. 2009). It is a fast-growing plant that achieves a height of 5 to 6m in about 4 to 5 months (Alexopoulou *et al*. 2000; Amaducci *et al*. 2000; Webber and Bledsoe 2002; Shukor *et al*. 2009). The increased commercial interest in using kenaf as a raw material for pulp and paper has led to the identification of its potential benefits (Osadare 1995; H'ng *et al*. 2009). Being a dicotyledon, kenaf has two distinct regions to its stem: outer bast (35 to 40%) and inner woody core (60 to 65%). Two major benefits identified to date are high yield and low lignin content. The low lignin content of kenaf is reflected in lower pulping chemical and energy consumption and lower bleaching requirements.

However, to use kenaf most effectively, it requires knowledge of not only the amounts of various substances that make up kenaf, but also how those substances contribute to the overall pulp and paper properties. The main focus of this study is to characterize the pulpsheet characteristics of kenaf grown in Nigeria relative to its fibre characteristics, chemical composition, and paper properties.

EXPERIMENTAL

Fibre Dimensions Measurement

The variety that was used in this study was the local variety from which a popular drink called *'Sobo'* is made. The kenaf bast fibre was obtained by decorticating the woody plant of a 3-month-old kenaf plant. The woody core was separated from the bast fibre, which was used for the study. Essentially this study focused on the bast as a substitute for imported long fibre pulp in Nigeria. The bast ribbon was later baled and transported to the mill site for investigation. From the bast fibres obtained, samples were taken and macerated using the Franklin method (1945). To achieve this, the kenaf bast was cut into short lengths of about 10 to 15 mm and placed in a mixture of equal volume of 30% hydrogen peroxide and 10% glacial acetic acid in a test tube and boiled in a water bath until soft and bleached white. The slivers were then washed, and dispersed in a 30 mL test tube containing 20 mL of distilled water. The macerated fibres were later mounted on a slide and projected in a Reichert visopan microscope. The length (L), diameter (D), and lumen width (d) of the projected fibres were measured on a visopan screen. The derived morphological indices, namely slenderness, flexibility, wall rigidity, and Runkel ratio were later calculated from the fibre characteristics.

Chemical Analysis

The proportions of the chemical constituents in the kenaf bast fibres were determined based on approved standards of Technical Association of Pulp and Paper Industry (TAPPI). The alcohol-benzene extractive, ash, and 1% alkali solubility of kenaf bast fibre were determined by TAPPI T12 os-75, T15 os-58, and T212 os-58, respectively. Similarly, the moisture content of the bast fibre, and the percentage of holocellulose, lignin, and pentosans were determined by TAPPI T12 os-75, T9m-54, T222 os-74, and T223 os-78, respectively. The percentage of alpha-cellulose, beta-cellulose, and gamma-cellulose were determined by TAPPI standard T203 os-74.

Pulping Experiment

Pulping was performed in a 25-litre electrically heated rotary laboratory digester at Federal Institute of Industrial Research, Lagos. For each cooking cycle, the liquor-to-bast fibre ratio, cooking time, and cooking temperature were kept constant at 4.5:1, 90 minutes, and 170 ^oC, respectively. Active alkali charge of 15% and sulphidity of 17.5% were used respectively. The cooking liquor was prepared in the laboratory at a ratio of 3:1 of sodium hydroxide to sodium sulphide. After each cook, a period of 20 minutes was allowed for gas down before the black liquor was ejected. All pulps were disintegrated, washed with cooled distilled water, and screened on a standard size 1 mm x 1 mm netted sieve. The pulping conditions as shown below were chosen based on preliminary experiments:

Liquor-to-bast ratio	4.5:1
Active alkali as Na_2O (%)	15.0
Sulphidity (%)	17.5
Maximum temperature (^oC)	170
Time to maximum temperature (min)	30
Time at maximum temperature (min)	90

Pulp Analysis

Pulp yield expressed as percentage of the oven dry weight of the chips was determined together with the rejects proportion. Kappa number measurement was determined as specified in the laboratory tests manual of Iwopin Pulp and Paper Company. The freeness of the unbleached pulp was tested using a Schopper Riegler Freeness tester, being the only freeness tester available in the kraft pulp mill at Jebba according to the guildelines in the laboratory manual. It was expressed as the rate at which water drained from a suspension of 3 g of pulp in 1 litre of water. The freeness was carried out between 10 ^oSR and 62 ^oSR, depending on the kappa number of the pulp.

Handsheet Preparation and Testing

The unbleached pulp was beaten in a PFI mill according to (TAPPI 1988). All the handsheets made at various level of beating and freeness were tested for burst, tear, breaking length, and stretch.

Pulp Bleaching

Bleaching was carried out in order to evaluate the possible utilization of bleached pulp of kenaf for tissue and bond paper production. The bleaching was done using 30%/vol. of hydrogen peroxide (P) in a vessel at 60^{o}C for 1 hour followed by alkali extraction (E) using sodium hydroxide at 80^{o}C. The laboratory was not equipped to carry out other expected experiments including viscosity and burst. The freeness tester used was a Canadian Standard Freeness tester.

RESULTS AND DISCUSSION

Fibre Dimensions and their Morphological Indices

The average fibre dimensions and their derived morphological indices are presented in Table 1. The fibre dimensions are among the most important indices for selecting a lignocellulosic fibre for pulp and paper making. The mean fibre length was 2.90 mm with fibre diameter of 28.16 µm, lumen width of 6.08 µm, and cell wall thickness of 11.04 µm. The average fibre length, diameter, lumen width, and cell-wall thickness of sample compared well with the fibre dimensions of kenaf varieties reported by H'ng *et al*. (2009) and Nkaa *et al*. (2007) and also were comparable to the range of 2.7 to 4.6 mm for softwood tracheids (Ates *et al*. 2008). The implication of this is that kenaf bast fibre could go a long way in alleviating the problems posed by a shortage of long-fibre pulp to Nigerian Paper mills. Similarly, kenaf bast fibres have remarkable derived morphological indices. The average slenderness, flexibility, and Runkel ratio of 105, 57% and 0.76 compared favourably with some softwood pulps (Ververis *et al*. 2004; Akgul and Tozlouglu 2009). Nkaa *et al*. (2007) reported that a low Runkel ratio of < 1 and a high flexibility ratio above 50% but less than 60% are necessary in fibres for papermaking. Fibres having these characteristics readily collapse and produce good surface contact in addition to fibre-to-fibre bonding. Therefore, papers made from kenaf bast are expected to have increased mechanical strength and thus be suitable for writing, printing, wrapping, and packaging purposes (Ververis *et al*. 2004; Saikia *et al*. 1997).

Table 1. Fibre Characteristics and Morphological Indices of *Hibiscus cannabinus* Bast

Fibre characteristics	Mean
Fibre length (mm) (*L*)	2.9
Fibre diameter (µm) (*D*)	28.16
Lumen width (µm) (*d*)	6.08
Cell-wall thickness (µm) (*w*)	11.04
Slenderness (*L*/*D*)	105:1
Flexibility (*l*/*D* x 100) (%)	57
Runkel ratio (2*w*/*d*)	0.76

Chemical Composition

The chemical composition of a lignocellulosic plant gives an idea of how feasible the plant material is for papermaking. The results of the average chemical composition of kenaf bast fibre are presented in Table 2.

The mean values of alcohol-benzene extractives of 0.7% and 1% alkali solubility of 15.2% are low. This indicates possible low pitch deposition and low rate of biological degradation. Pitch problems are often associated with high-extractive trees like pine. Similarly, the low percentage of ash (0.6%), lignin (12.5%), and pentosans (10.6%) in the kenaf bast is an indication that low amount of pulping liquor will be required to pulp the kenaf bast. Kristova *et al*. (1998) opined that high ash content will affect normal alkali consumption and give problems with waste liquor recovery. Ververis *et al*. (2004) also suggested that the presence of low percentages of lignin and ash indicates that milder pulping conditions (lower temperature and chemical charges) will be required to pulp kenaf compared to softwood and hardwoods.

Meanwhile, the cellulose content of the kenaf bast is high. The combination of cellulose and hemicellulose is called holocellulose. The results of the chemical analysis of Nigerian grown kenaf showed that holo-cellulose accounted for 73.2% of kenaf bast, while the alpha-cellulose accounted for 55.5% (Table 2) . These values are quite high. According to Nieschlag *et al*. (1960) plant materials with alpha-cellulose of 34% and above are characterised as promising for pulp and paper manufacture from a chemical composition point of view. It has been shown that cellulose and aplha-cellulose content can be correlated with yields of unbleached and bleached pulps respectively (Wood 1981). The amount of soluble cellulose, which includes beta-cellulose (14.8%) and gamma-cellulose (2.9%), also attests to the expected pulp yield of kenaf bast. However, the appreciable amount of beta-cellulose (14.8%) also coroborated the fact that a milder pulping condition might be needed to pulp kenaf bast, as beta-cellulose constitutes the fraction of cellulose that might be degraded during pulp washing.

Table 2. Chemical Analysis of *Hibiscus cannabinus* Bast

Properties	Bast
Alcohol-Benzene (%)	0.7
1% alkali solubility (%)	15.2
Ash (%)	0.6
Lignin (%)	12.5
Pentosan (%)	10.6
Holocellulose (%)	73.2
Alpha-cellulose (%)	55.5
Beta-cellulose (%)	14.8
Gamma-cellulose (%)	2.9

Pulp Properties of Unbleached Kraft Pulp of Kenaf Bast

The effect of pulping parameters, which include active alkali charge and sulphidity of the pulping liquor, on screen yield and kappa number of unbleached pulp is presented in Table 3. It could be observed that the average screen yield of the pulp was a bit higher at the specified sulphidity of 17.5% and active alkali of 15.0%, respectively;

however, the variation observed in kappa number may be attributed to some abnormality encountered during pulping operation (electricity failure). Denis *et al*. (2004) reported that the effect of alkali charge on pulp properties is more important than that of sulphidity. An increase in percentage of active alkali charge of pulping liquor could result in low pulp yield.

Meanwhile, kappa number is an indication of the bleachability of the pulp. It estimates the amount of chemicals required during bleaching of wood pulp to obtain a pulp with a given degree of brightness. Since the amount of bleach needed is related to the lignin content of the pulp, the kappa number can be used to monitor the effectiveness of the lignin-extraction phase of the pulping process (Biermann 1993). The highest pulp yield of 52.8% was attained when the kappa number was 18.5 at an active alkali charge of 15.0% and sulphidity of 17.5%. When kappa number increased beyond a level, (in this case 18.5), the yield was equally low (Fig.1); it could be inferred that low kappa number is associated with low yield. (Table 3).

The results of the testing of physical properties of the unbleached pulp are presented in Table 4. The unbleached pulps were beaten in a PFI mill between 0 and 5000 revolutions, and handsheets were prepared for physical properties. The ^{o}SR value of the pulp increased insignificantly from the range 10-55 at a kappa number of 16.5 to the range 19-62 at a kappa number of 20.4 after 5000 PFI revolutions ($p < 0.05$). The ease of beating of the pulp can be explained by the milder pulping conditions required and the low lignin content of the pulp. Other strength properties were significantly affected. The breaking length (4.71 Km) and burst factor (46.47 kPa-m^2/g) were highest when the pulp was beaten at a freeness level of 10 to 55^{o}SR at a kappa number of 16.5. The tear factor was much higher than hardwood (Adeogun and Sotannde 2007). The tear factor of 298.4 mN.m^2/g was the highest in pulp with freeness level between 20-52 ^{o}SR and a kappa number of 20.5. The high fibre length and cell wall thickness of kenaf bast might be the reason for the high tear factor. Meanwhile, the relationships between pulp freeness strength properties at the optimum yield of the unbleached pulp of 52.8% and kappa number of 18.5 are presented in Figs. 2 and 3. It was observed that at varying freeness level, the strength of the unbleached was greatly enhanced. All these show that kenaf bast has strength properties similar to softwood.

Table 3. Alkali Charge, Kappa Number and Screened Yield of Unbleached Kraft Pulp of Kenaf Bast*****

Cook number	Active alkali ($\%Na_2O$)	Sulphidity (%)	Kappa number	Screen yield (%)
1	15.0	17.5	16.5	51.5
2	15.0	17.5	18.5	52.8
3	15.0	17.5	14.8	50.8
4	15.0	17.5	12.0	48.8
5	15.0	17.5	20.5	51.2
6	15.0	17.5	20.4	52.6
*Maximum temperature (170^{o}C); pulping time (90 minutes)				

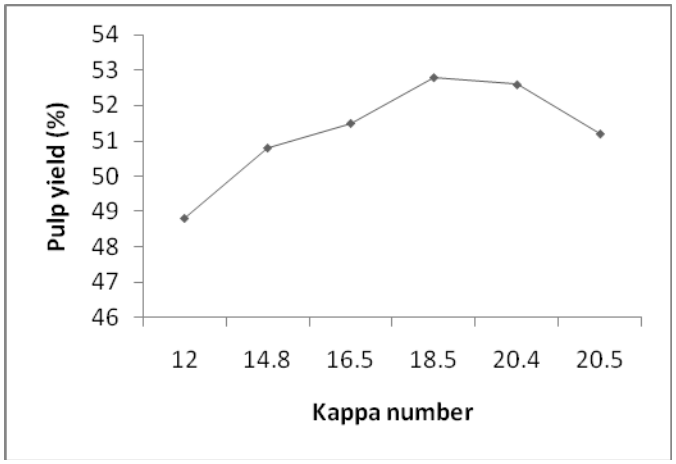

Fig. 1. Relationship between kappa number and screen yield of unbleached kraft Pulp of kenaf bast

Table 4. Properties of Unbleached Kenaf Bast Kraft Pulp Produced at Optimum Active Alkali and Sulphidity

Cook No	1	2	3	4	5	6
Kappa No	16.5	18.5	14.8	12.04	20.5	20.4
Freeness (^{o}SR)						
Range	10-55	15-55	15-51	18-56	20-52	19-62
Mean	29.6	34.2	31.8	36.6	38.0	39.6
Basis weight (g.s.m)						
Range	96-105	100-110	99-101	99-103	100-105	98-106
Mean	100.4	103.4	100.0	101.2	102.0	101.0
Caliper (mm)						
Range	0.21-0.24	0.20-0.39	0.32-0.41	0.35-0.45	0.36-0.43	0.32-0.42
Mean	0.22	0.26	0.36	0.40	0.39	0.37
Bulk (cm^3/g)						
Range	1.97-2.40	2.00-3.67	3.17-4.13	4.05-4.95	3.60-4.22	3.26-4.24
Mean	2.17	2.48	3.58	4.28	3.84	3.62
Breaking length (Km)						
Range	3.74-5.66	1.28-3.28	2.51-4.46	2.95-3.88	2.16-3.99	2.84-3.40
Mean	4.71	2.68	3.44	3.44	3.04	3.17
Stretch (%)						
Range	1.38-2.41	1.47-2.43	1.53-2.75	1.23-2.61	0.99-2.06	1.52-1.98
Mean	1.93	2.00	1.83	1.91	1.68	1.75
Tear index (mN.m^2/g)						
Range	6.9-28.3	16.0-35..2	20.0-28.4	19.4-26.2	22.4-39.6	24.2-32.6
Mean	14.46	24.86	23.90	22.38	29.84	27.04
Burst factor (kPa.m^2/g)						
Range	38.59-55.0	26.19-43.70	27.50-46.72	27.07-38.74	17.25-33.50	21.34-30.56
Mean	46.47	37.09	35.33	33.02	26.69	25.38

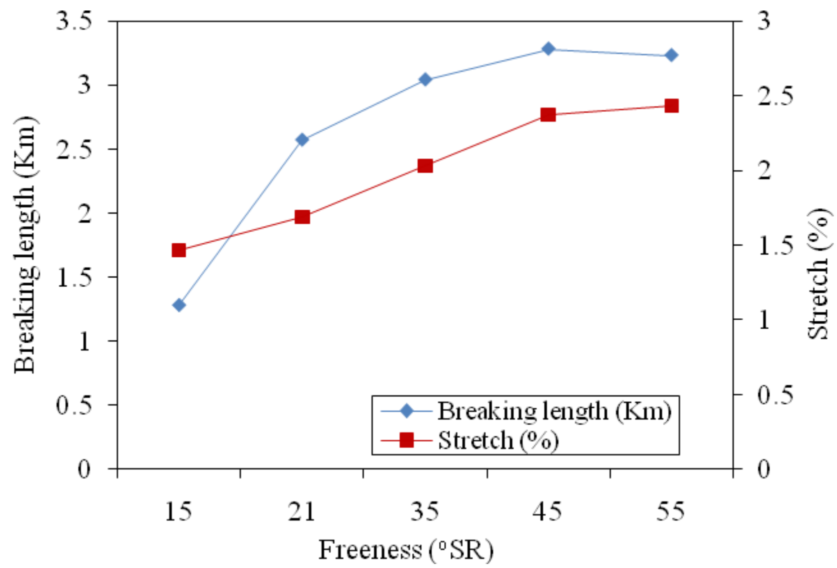

Fig. 2. Effect of freeness on breaking length and stretch of unbleached kraft pulp of kenaf bast

To evaluate the effect of beating on the bleached pulps obtained, the strength properties of bleached handsheets were determined at different degrees of beating. The physical strength properties of bleached pulp carried out in a laboratory valley with 0, 1000, 2000, 3000, 4000, and 5000 revolutions is given in Table 5. The results indicate that bleached kraft pulp of kenaf bast gave an unbeaten freeness of 550 mL, while the tear index, tensile strength, and stretch were 11.84 mN.m^2/g, 2.09 km, and 3.94%, respectively. Similarly, the basis weight, drainage, and brightness of the unbeaten bleached pulp were 62 gsm, 4.98 seconds, and 61.2%, respectively. But when the revolutions of beating were increased from 1000 to 5000, the freeness of the pulp decreased considerably (Table 5), giving substantial improvement in the physical strength properties of the bleached pulp. At a freeness of 148 mL, tensile and stretch improved considerably while tear decreased. For example, while tensile strength and stretch increased from 3.30 to 4.80 kN/m and 3.74 to 4.39% respectively, tear index decreased from 10.00 to 6.40mN m^2/g. This is expected, as less energy will be required to pull the fibre apart. This finding is in line with the results of Jahan *et al*. (2007) on Jute fibres and Nezamoleslami *et al*. (1997) on kenaf bast. Significant improvement in pulp brightness varied inconsistently from the unbeaten state to the final state, as shown in Table 5.

Table 5. Properties of Bleached Kraft Pulp of Kenaf Bast

Beating revolution	Unbeaten	1000	2000	3000	4000	5000
CSF(mL)	550	508	405	336	189	148
Basis weight (g.s.m)	62	60	59	59	62	59
Tear (mN m^2/g)	11.84	10.00	7.20	6.89	6.60	6.40
Tensile strength (kN/m)	2.09	3.30	4.35	4.63	4.78	4.80
Stretch (%)	3.94	3.74	3.81	3.86	4.18	4.39
Drainage time (Secs)	4.98	4.55	5.89	7.99	10.34	18.40
Brightness (%)	58.0	58.6	58.8	61.2	59.7	59.6

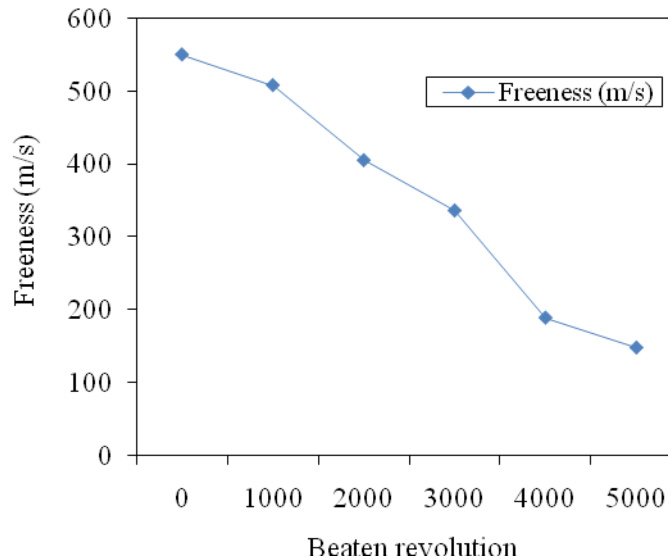

Fig. 3. Effect of beating revolution on freeness of bleached kraft pulp of kenaf bast

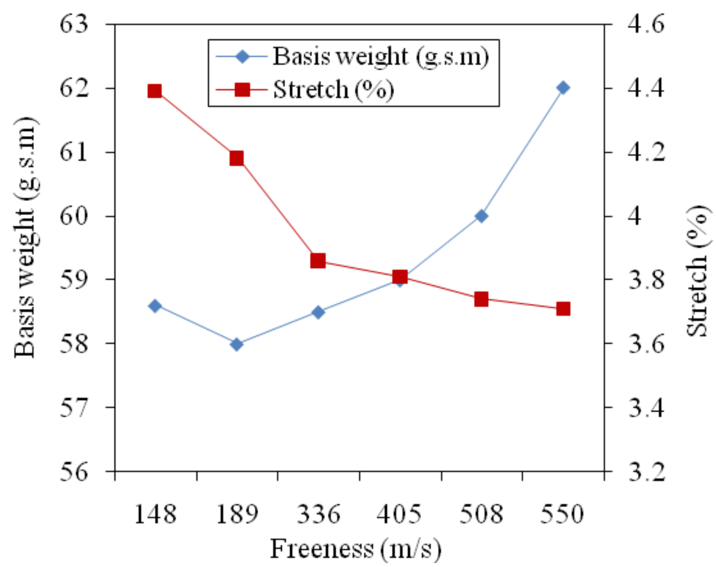

Figure 4. Relationship of pulp freeness with basis weight and stretch of bleached kraft pulp of kenaf bast

CONCLUSIONS

1. From the results of this experiment, it is obvious that kenaf bast can play a significant role in reducing the high cost associated with the importation of long-fibre pulp to the pulp and paper mills in Nigeria.
2. The bast of Nigerian grown kenaf has great similarity with softwoods. The average fibre length, flexibility, and Runkel ratio were found to be 2.90 mm, 57%, and 0.76, respectively, which shows that paper from kenaf bast can have mechanical strength similar to that of softwood.

3. The low percentage of ash, lignin, and pentosans in the kenaf bast showed that milder pulping condition will be required to pulp kenaf bast compared to both softwoods and hardwoods. However, the high percentage of holocellulose and alpha cellulose corroborated the high screen yield of kenaf pulp, which stood at between 48.8 and 52.8% at a kappa number of 12.04 to 20.5.
4. Analysis of the pulp properties showed that kenaf bast can be easily pulped using the kraft pulping method to a low kappa number with acceptable yield. The highest screen yield of 52.8% at a kappa number of 18.5 was quite remarkable.
5. The burst factor, tear index, breaking length (tensile strength), and stretch of kenaf bast showed much similarity to softwood pulp.

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