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The Kraft Pulp And Paper Properties of Sweet Sorghum Bagasse (*Sorghum bicolor* L Moench)

Widya Fatriasari[1], Supriyanto[2] & Apri Heri Iswanto[3]

[1]Research Center for Biomaterials LIPI
Jalan Raya Bogor KM 46, Cibinong, Bogor 16911, Indonesia
[2]SEAMEO BIOTROP, Jalan Raya Tajur Km 6, PO Box 116, Bogor 16134, Indonesia
[3]Forestry Department, Forestry Faculty, North Sumatera University,
Jalan Prof. A. Sofyan No.3 Kampus USU, Medan 20155, Indonesia
Email: widya_fatriasari@yahoo.com

Abstract. This study investigated the potency of sweet sorghum (*Sorghum bicolor*) bagasse as raw material for pulp and paper using kraft pulping. The effects of alkali and sulfidity loading on kraft pulp and paper properties were also investigated. The pulping condition of the kraft pulp consisted of three levels of alkali loading (17, 19 and 22%) and sulfidity loading (20, 22 and 24%). The maximum cooking temperature was 170°C for 4 h with a liquid to wood ratio of 10:1. Kraft pulping of this Numbu bagasse produced good pulp indicated by high screen yield and delignification selectivity with a low Kappa number (< 10). The unbleached pulp sheet produced a superior brightness level and a high burst index. The increase of active alkali loading tended to produce a negative effect on the pulp yield, Kappa number and paper sheet properties. Therefore, it is suggested to use a lower active alkaline concentration.

Keywords: *alkali and sulfidity loading; kraft pulping; pulp and paper properties; sweet sorghum bagasse.*

1 Introduction

The deforestation rate in the world due to wood and paper demand is estimated at about 11.2 million hectares per year [1]. Therefore, the pulp and paper industry should find out alternative raw materials, particularly non-wood fiber coming from agricultural wastes [1,2] that are annually highly available. On the other hand, concerns about sustainable future fiber supplies and a potential increase in wood cost also stimulates the pulp and paper industry to find out other fiber sources, such as sorghum [2]. Sorghum is a C_4 crop characterized by very efficient photosynthesis, which can grow quickly [1,3] and has wide range adaptability. Sweet sorghum produces a high yield of green biomass and a huge amount of ligno-cellulosic residue [4,5]. This biomass is renewable, cheap and widely available. The residue produced by juice extraction from the stalk, the so-called bagasse, represents about 30% of the whole plant fresh weight [6] and is used for non-food applications containing carbohydrate polymers (cellulose and hemicellulose) and lignin. Sorghum bagasse contains 40-49% cellulose,

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which is important for pulp production, with a cutting cycle at 3 months after planting. Meanwhile, fast-growing species such as *Acacia mangium* and *Eucalyptus urophylla*, containing 60% of cellulose, need 7 years for producing 120 tons of cellulose/ha/7 years. The cellulose production of sweet sorghum can reach 15 tons/ha/3 months or 60 tons/ha/1 year or 420 ton/ha/7 years, which is considerably higher than the production of *A. mangium* and *E. urophylla* [7].

Pulp of sweet sorghum can be used for the manufacture of fine quality writing paper, low luminosity printing paper and kraft paper as well as corrugated solid particleboard [1,2]. Investigation on sorghum fiber for pulp production has been conducted in India [1] using a conventional soda pulping process, where the average pulping yield was 45% and the Kappa number was 14-18. The pulp is characterized by short fibers and a high proportion of fines. The production of sorghum stalk pulp needs fewer chemicals than the production of woody pulp, so it is quite suitable for making quality paper. Kumar and Marimuthu [2] pulped the biomass using the same method with an alkali concentration (as Na_2O) of 13% at 165°C.

In kraft pulping, both sulfidity and active alkali are two important factors that affect the pulp and paper properties [8], while kraft pulp strength properties can be improved by optimizing the pulping condition. The objective of this research was to investigate the chemical liquor loading effect on the properties of pulp and paper made of sweet sorghum bagasse.

2 Materials and Methods

2.1 Material Preparation

Bagasse from the Numbu variety of sweet sorghum (derived from BIOTROP plants, Bogor, Indonesia) was obtained after juice extraction for ethanol production. The bagasse was manually chopped to obtain a chip length of ± 4-5 cm and then processed by drum chipper and hammer mill to obtain a chip length of 2-3 cm. To remove impurities contained in the samples, the chips were boiled for 1 h at 100°C. Subsequently this treatment was followed by washing with clean water for 3 times, and then drying, both by air and oven at 40°C, to obtain ± 7-10 % moisture content. The treated chips were subjected to chemical analysis and pulping experiments. Technical grade chemicals (NaOH and Na_2S) were purchased from Bratachem, Bogor, Indonesia.

2.2 Chemical Analysis and Pulping Process

Chemical analysis was performed based on protocols from the Mokushitsu Kagaku Jiken Manual using treated sweet sorghum bagasse powder. The

Numbu bagasse chips (250 g oven dried weight) were kraft pulped using three levels of active alkali, i.e. 17, 19, 22% and 20, 22, 24% of sulfidity loading for 1.5 h to reach maximum temperature and 2.5 h at 170°C and a liquor to fiber ratio of 10 relative to dry matter. After pulping, the softened chips were washed to remove residual alkali in the pulp, followed by separation of the black liquor and pulp. The pulp was then analyzed for its Kappa number (TAPPI T236 cm-85), degree of freeness (TAPPI T227 om-92 1992) and pulp yield (TAPPI T210 cm-93). The delignification selectivity was then determined as the ratio of carbohydrates and lignin in the pulp. Lignin content in the pulp was calculated as a function of the Kappa number.

2.3 Sheet Formation and Pulp Sheet Property Testing

To improve fiber bonding in sheet formation, the pulp suspension was blended previously, after which pulp sheet formation was performed according to SNI 14-0489-1989 with a gramature target of 80 g/m^2. Physical property testing of pulp sheet comprised of tensile strength (SNI 14-4737-1998), tear strength (SNI 14-0436-1989), burst strength (SNI 14-0436-1989), breaking length (SNI 14-0439-1989) and optical property (brightness level) (SNI 14-0438-1998) testing.

3 Results and Discussion

3.1 Chemical Component of Sweet Sorghum Bagasse

The ideal raw material for forming a pulp and paper with good characteristics is a material with high cellulose content but low lignin, extractives and ash content. The chemical properties of the Numbu sweet sorghum after pretreatment are shown in Table 1. Based on the classification grades of the chemical components of Indonesian wood [9], this result indicates that the cellulose, lignin and extractive content of this Numbu variety can be categorized as medium class, while the hemicellulose content of the bagasse was quite high. In general, conversion of this material to pulp will produce a good quality pulp [10]. A high content of extractives in the material causes a lower pulp yield and sheet brightness [11]. Bagasse with lower ethanol-benzene extractive contents (<5%) is categorized as good and can be used to predict the formation of good pulp properties. Residual lignin in pulp causes unfavorable effects, both on the color and physical properties of the pulp due to inhibition activity of cellulose and hemicellulose on internal fiber bonding formation [12]. The hollocellulose content of the Numbu bagasse was higher than that in a previous study by Kumar and Marimuthu [2] on both sweet sorghum stalk and bagasse in India. The lignin and hemicellulose content of the Numbu bagasse differed while its extractive content was comparable with that of the two types of bagasse previously reported.

Table 1 Chemical properties of sorghum bagasse.

Chemical Component	Content (%)	Classification Grade[1]	Pulp Quality[2]	Previous Study[3] (%)	
				Sweet Sorghum Stalks	Depicted Bagasse
Et-ben extractives	2.87±1.21	Medium	Good	2.8	2.2
Klason lignin	24.98±0.35	Medium	Good	17.4	20.0
Holocellulose	73.03±1.74	-	Good	67.2	60.0
Alpha cellulose	42.36±1.51	Medium			
Hemicellulose	30.67±1.51	High		27.3	19.0

[1] Agriculture Departement [9]
[2] FAO *in* Syafii and Siregar [10]
[3] Kumar and Marimuthu [2]

Based on the parallel study of fiber morphology done by Iswanto, *et al*. [13], the Numbu strain fiber was categorized as Class II (1000-2000 μm of fiber length) (Indonesian wood fiber criteria as raw material of pulp and paper reported by LPHH (Forest Product Research Report) [14] and was predicted to produce a fairly good pulp. The total score in derived dimension value including fiber length of the Numbu strain fiber was < 300 (Table 2), which means that this fiber could be classified as Grade III-IV [14]. Pulp sheet from Numbu fiber will produce a rough and thick sheet with high tear strength but low tensile strength.

Table 2 Fiber properties and score of sweet sorghum fiber as raw material for pulp.

Fiber properties	Grade		
	Required Standard [9]	Value [13]	Score [9]
Fiber length (μm)	900-1600	1291	50
Runkel ratio	1.0	1.67	25
Felting power	70-90	75.8	75
Muhlstep ratio %	60-80	80.95	25
Flexibility ratio	0.40-0.60	0.42	50
Rigidity Coefficient	0.20	0.29	25
Total score			**250**

[9] Agricultural departement

3.2 Pulp Properties

3.2.1 Pulp Yield

Screened pulp yield against chemical loading differences is presented in Figure 1, which shows that the pulp yield was affected by active alkali and sulfidity loading differences. These results are in line with Rahmiati, *et al*. [8] and Fatriasari and Risanto [15], who used *E. camaldulensis* and *P. falcataria* wood as kraft pulp raw material, respectively. These reports indicate that the charge of chemical pulping tends to affect the pulp yield, Kappa number, viscosity, and pulp brightness as well.

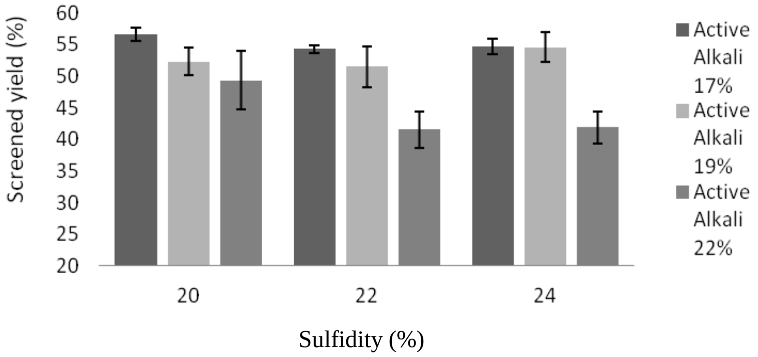

Figure 1 Effect of active alkali and sulfidity loading on screened pulp yield.

An increased alkali concentration tended to decrease the screen pulp yield while an increased sulfidity did not show a constant effect on pulp yield improvement. Even though a sulfidity of 22% tended to cause a decrease in pulp yield, an increase of the sulfidity concentration affected the pulp yield improvement. The highest pulp yield was achieved from a pulping condition with 20% sulfidity and 17% active alkali while the lowest value was at 22% for both active alkali and sulfidity. This means that utilization of a higher sulfidity charge provides a better pulp yield than a lower sulfidity loading with the same alkali concentration. This result can be caused by delignification in the kraft pulp involving hydrosulfide (HS^-) and sulfide ions, which is selective to maintain more cellulose compared to NaOH. These ions accelerate the delignification process by attacking β aryl ether bonds and thus preserving the pulp yield [16,17]. Acceleration of delignification produces more lignin degradation compared to degradation of its glycoside bonds. In addition, these ions prevent the decrease of carbohydrates because of stabilization at the end group of the cellulose chain. Basically, the use of NaOH as cooking solution serves to remove the lignin and promote the separation of fibers. These activities cause a decrease in pulp yield. Therefore, it is better to use a lower active alkaline concentration, because an increase in alkali concentration leads to a decrease in pulp yield.

3.2.2 Kappa Number

The Kappa number shows the residual lignin content of the pulp. This number can serve for the comparison of lignin content among treatments. Pulp with a good delignification degree will have a lower Kappa number, thus the lower the

Kappa number, the more complete the delignification process. A smaller quantity of bleaching chemicals is expected to be required to produce bleached pulp. According to Casey [12], a Kappa number higher than 20 means that it is not feasible to bleach the pulp because it requires too much bleaching chemicals.

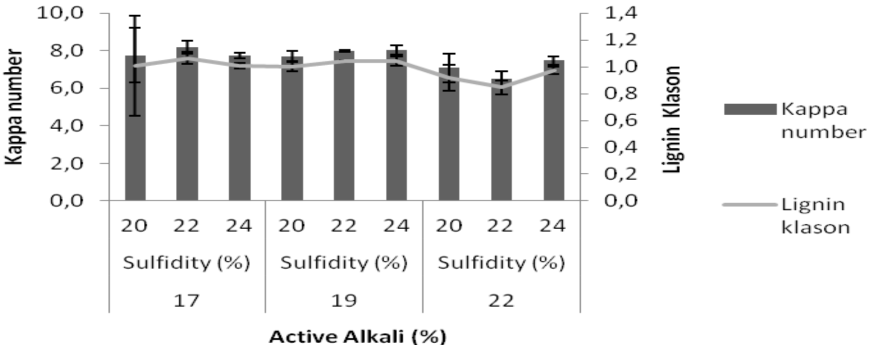

Figure 2 The effect of active alkali and sulfidity loading on Kappa number and klason lignin of pulp.

The average Kappa numbers of the pulp were 6.51-8.20. The highest value was for the treatment with 17% active alkali and 22% sulfidity, while the lowest value was for pulping with 22% for both active alkali and sulfidity. The increase of sulfidity loading did not significantly affect Kappa number reduction. This means that all cooking conditions provided a good delignification activity in the material. The increase of sulfidity concentration is expected to be more dominant than that of alkali in influencing Kappa number reduction. These results are in line with our previous result [15], but contradict the study of Rahmiati, *et al*. [8] that lignin removal efficiency occurs with an increase of sulfidity loading. In the cooking process, the sulfidity is also determined by the chemical equilibrium: it is higher in closed-cycle pulping and lower in an open-cycle process. Optimum sulfidity depends on several factors, such as the type of biomass, alkali concentration, cooking temperature and expected properties of the final pulp. The active alkali concentration has a negative effect on the Kappa number, but the sulfidity concentration does not.

Klason lignin is a function of the Kappa number of pulp, where a high Kappa number reflects a high content of lignin remaining in the pulp. In this case, pulping conditions using 17% active alkali and 22% sulfidity produced the highest residual lignin, while the treatment with 22% active alkali and sulfidity provided the lowest value (Figure 2). Compared to the initial lignin content of the Numbu bagasse, the highest and lowest lignin reduction were 96.76% and

95.73%, respectively. This means that the cooking conditions used were relatively effective for dissolving/delignification of lignin polymers. Lignin, which swells in kraft pulping of bagasse chips, is chemically broken down into fragments of hydroxyl (OH-) and hydrosulfide (SH-) ions in liquid chemical pulping. The lignin fragments then dissolve in the form of phenolate or carboxylate ions [18].

3.2.3 Delignification Selectivity

Selectivity of delignification is a measurement of the effectiveness of the pulping process. High delignification selectivity means that the attack of lignin is more selective than that of carbohydrate in the pulp during the pulping process [17].

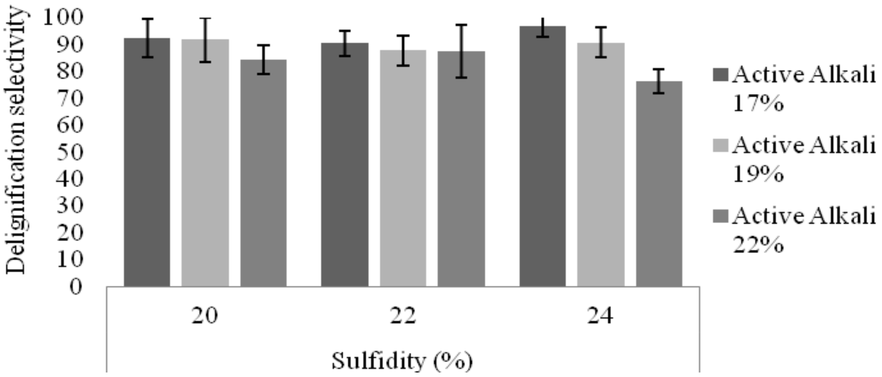

Figure 3 The effect of active alkali and sulfidity laoding on delignification selectivity of pulp.

Figure 3 shows that the delignification selectivity value ranged from 76.29-96.66 while the highest selectivity delignification ratio was for a pulping condition using 17% active alkali and 24% sulfidity and the lowest selectivity delignification ratio was for utilization of active 22% alkali and 24% sulfidity. All treatments showed high values for this parameter, which means that lignin degradation activity was higher than that of carbohydrate (cellulose and hemicellulose) hence these kraft pulping conditions are suitable for converting Numbu bagasse chips into pulp.

3.2.4 Physical Properties of Pulp Sheet

In general, the pulping conditions produced pulp properties with a lower tear index than unbleached kraft and did not meet the requirements of the burst index for unbleached kraft pulp from softwood, except the treatment using 19% active alkali and 22% sulfidity (Table 3). The increasing active alkali tended to decrease the burst index, except for the treatment using 20% sulfidity. This result is in line with the previous study by Sukaton [19], in which increased active alkali had a negative effect on paper sheet properties.

Tear strength is related to felting power, where the greater the strength, the higher the tear strength and the better the felting power. Long fibers produce high tear strength, related to the formation of fiber contact on a wider surface area than that of short fibers [10]. A better internal fiber bonding potential can be given by long fibers [20] and long fibers in pulp and paper can improve the tear strength of paper [21]. Internal fiber bonding produces paper sheets with high tear strength and density [22]. The same trend that is due to the increase of sulfidity and active alkali concentrations cannot be seen in the tear index value. The highest tear index value was obtained with the treatment of 19% active alkali and 20% sulfidity (Table 3). All values were lower than the required values for unbleached pulp sheet (9.0 Nm^2kg^{-1}). The increase of active alkali also had a negative effect on this strength [19].

Table 3 Influence of chemical loading treatment on physical and optical pulp sheet properties.

Pulping Condition		**Gramature ($g\ m^{-2}$)**	**Tensile Index (Nmg^{-1})**	**Tear Index (Nm^2kg^{-1})**	**Burst Index ($Kpa.m^2g^{-1}$)**	**Breaking Length (km)**	**Brightness Level (%)**
Active Alkali (%)	**Sulfidity (%)**	**SNI 14-0489-1989**	**SNI 14-4737-1998**	**SNI 0436-2006**	**SNI 14-0439-1989**	**SNI 14-4737-1998**	**SNI 14-0438-1998**
17	20	82.7243	5.3189	2.6244	0.2236	0.53	47.81
17	22	79.6782	3.5141	3.2832	0.2912	0.35	48.32
17	24	80.6206	3.7211	2.6581	0.2208	0.39	47.93
19	20	75.1634	4.3904	3.5323	0.2608	0.41	44.54
19	22	81.7568	3.5471	2.3815	0.2177	0.36	42.66
19	24	75.1941	2.9258	2.8859	0.,2075	0.30	43.99
22	20	79.7884	3.1333	2.5881	0.2344	0.31	46.84
22	22	76.1295	1.8390	2.4182	0.1642	0.19	46.87
22	24	79.8502	2.2542	1.8610	0.1916	0.22	46.16

The breaking length of all treatments is also related to the derived dimension values of the fiber such as felting power and flexibility ratio. A high flexibility ratio means a big lumen diameter of the fiber and a small fiber diameter. A higher flexibility ratio means a better breaking length of the pulp. The breaking length in this research did not meet the minimal requirements for grade classification based on the evaluation criteria for kraft pulp properties for hardwood. The breaking length had a trend similar to the tensile index affected by the fiber length.

Brightness has a high correlation with the residual lignin content of pulp. An increase in brightness means a decrease in lignin content and the Kappa number in the pulp [23]. The brightness obtained in this study was high; this value was higher than the brightness range of unbleached kraft pulp (15-30% ISO). Utilization of 19% active alkali produced a brightness level of paper sheets that was lower than for the other treatments (Table 3). There was a tendency that the increase to 19% active alkali reduced the brightness level but then it improved again at 22% active alkali.

4 Conclusions

The shorgum bagasse fiber has a high cellulose content, low lignin and extractive content, medium fiber length, wide lumen fiber with high felting power. Kraft pulping of the Numbu bagasse produced in this research had good properties, such as a high screen yield and delignification selectivity, and low Kappa number (below to 10). The unbleached pulp sheet produced a superior brightness level and high burst index. The increase of active alkali loading tended to have a negative effect on the pulp yield, the Kappa number and paper sheet properties. Therefore it is better to use a lower active alkaline concentration.

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