THE KRAFT PULP AND PAPER PROPERTIES OF SWEET SORGHUM BAGASSE (*Sorghum bicolor* L Moench)

Abstract This study was to investigate the potency of sweet sorghum (*Sorghum bicolor*) bagasse as raw material for pulp and paper using Kraft pulping. The effect of alkali and sulfidity loading on kraft pulp and paper properties was also investigated. The pulping condition of 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^{0}C for 4 hours with 10:1 of liquid to wood ratio. Kraft pulping of this Numbu bagasse produced good properties on high screen yield and delignification selectivity, low Kappa number (< 10). This unbleached pulp sheet produces superior brightness level and the high burst index. The increase of active alkali loading tends to produce negative effect on 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

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

Received ________, Revised ________, Accepted for publication __________

at 3 months after planting. Meanwhile, fast growing species such as *Acacia mangium* and *Eucalyptus urophylla* contain 60% of cellulose, have 7 years for producing 120 tons of cellulose/ha/7 years. The cellulose production of sweet sorghum could achieve 15 tons/ha/3 months or 60 tons/ha/years or 420 ton/ha/7 years and this yield is higher than *A. mangium* and *E.urophylla's* production [7].

Pulp of sweet sorghum can be used for the manufacture of fine quality writing and low luminosity printing paper and kraft paper as well as corrugated solid particle board [1,2]. Investigation on sorghum fiber for pulp production has been conducted in India [1] using conventional soda pulping process where the average pulping yield was 45% and kappa number was 14-18. The pulp is characterized by short fibers and high proportion of fines. The production of sorghum stalk pulp only needs fewer chemicals than producing woody pulp, so it is quite suitable to be used for making quality paper**.** Kumar and Marimuthu [2] also pulped the biomass using the same method with 13% of alkali concentration (as Na_2O) at 165^0C.

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

2 Materials and Methods

2.1 Material Preparation

Bagasse of sweet sorghum Numbu variety, was derived from BIOTROP plants, Bogor, Indonesia, was obtained after juice extraction for ethanol production. Bagasse was manually chopped to obtain ± 4-5 cm of chip length and then was processed by drum chipper and followed by hammer mill to obtain chip size at 2-3 cm length. To remove impurities contained in samples, the chips were boiled for 1 h at 100^0C; subsequently this treatment was followed by washing with clean water for 3 times, and then drying, both of air and oven at 40^0C to obtain ± 7-10 % moisture content. The treated chips were subjected to chemical analysis and pulping experiments. The chemicals (NaOH and Na_2S) in technical grade were purchased from Bratachem, Bogor, Indonesia.

2.2 Chemical Analysis and Pulping Process

Chemical analysis was determined using treated sweet sorghum bagasse powder.performed based on Mokushitsu Kagaku Jiken Manual protocols.The Numbu-bagasse chips (250 g of 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 170^0C, and liquor to fiber ratio of 10 relative to dry matter. After pulping process, the softened chips were washed to remove residual alkali in the pulp, and then 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 ratio of carbohydrates and lignin in the pulp. Lignin in the pulp was calculated from kappa number function.

2.3 Sheet Formation and Pulp Sheet Property Testing

To improve fiber bonding in sheet formation, the pulp suspension was blended previously and then pulp sheet formation was performed according to SNI 14-0489-1989 with 80 g/m^2 of gramature target. Physical property testing of pulp sheet was 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).

3 Results and Discussion

3.1 Chemical Component of Sweet Sorghum Bagasse

The ideal raw material used to form a good characteristic of pulp and paper is a material with high cellulose content but low lignin content, extractives and ash. Chemical properties of sorghum Numbu variety after pretreatment are shown in Table 1. Based on classification grades of Indonesian wood chemical component [9], this result indicated that the cellulose, lignin and extractives of this Numbu variety were categorized in medium class, while hemicellulose content of bagasse was quite high. In general, conversion process of this material to pulp will produce a good quality pulp [10]. A high content of extractives in materials causes a lower pulp yield and sheet brightness [11]. Lower ethanol-benzene extractives (<5%) in bagasse is included in good category that can be used to predict the formation of a good pulp properties. Residual lignin in pulp causes unfavorable effects, both on the color and physical properties of pulp due to inhibition activity of cellulose and hemicellulose to internal fiber bonding formation [12]. This hollocellulose content of Numbu bagasse is higher than previous study both on sweet sorghum stalk and depicted bagasse in India of Kumar and Marimuthu [2]. Lignin and hemicellulose content of this material was in contrary while its extractive content is comparable with 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 extractive	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], Numbu strain fibers are categorized in quality of 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 they are predicted producing a fairly good pulp. The result of total score in derived dimension value including fiber length of Numbu strain fibers is < 300 (Table 2), which means this fiber was included in the quality of grade III-IV [14]. Pulp sheet formation of Numbu fibers 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

The screened pulp yield on the cooking chemical loading difference is presented in Fig 1, which shows that pulp yield was affected by alkali active and sulfidity loading differences. These results are in line both of Rahmiati *et al*. [8] and Fatriasari and Risanto [15] with *E.camaldulensis* and *P.falcataria* woods as kraft pulp raw material respectively. These reports indicated that the charge of chemical pulping tends to affect the pulp yield, kappa number, viscosity and pulp brightness as well.

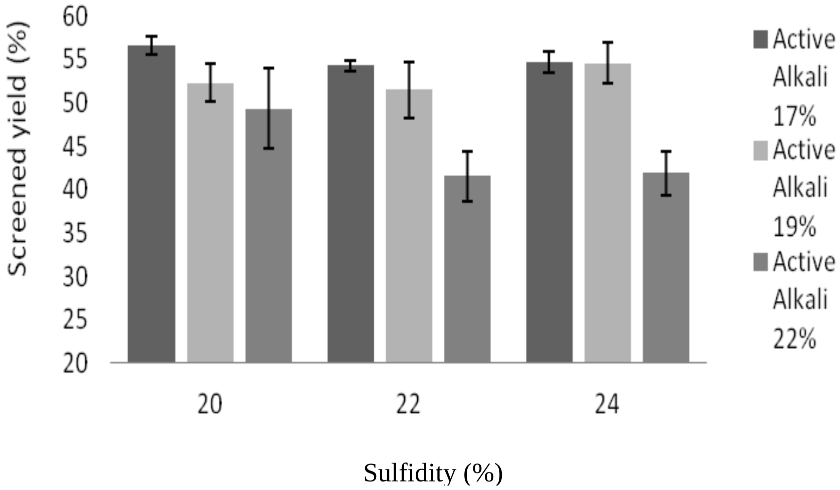

Figure 1 The efect of active alkali and sulfidity loading on screened pulp yield

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

3.2.2 Kappa Number

Kappa number shows the residual lignin content of pulp. The numbers can serves for the comparison of lignin content among treatments. Pulp with good delignification degree will give lower kappa number, thus the lower kappa numbers, the more complete delignification process. The bleaching chemical to produce bleached pulp is expected to require less quantity. According to Casey [12], kappa number of pulp higher than 20 means that it is not feasible to bleach because it requires many bleaching chemicals.

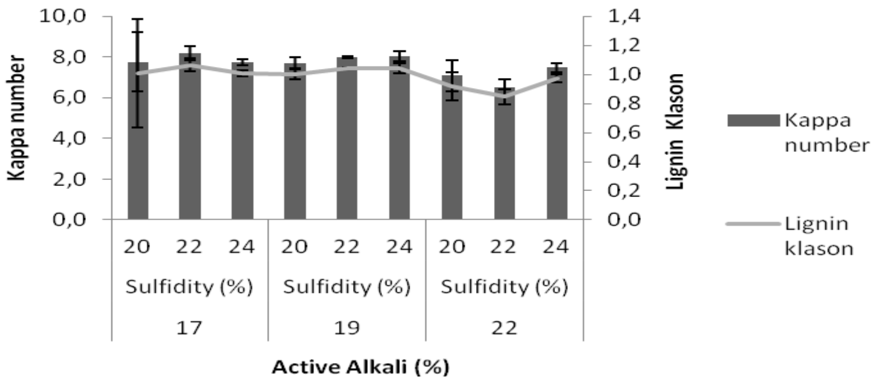

Figure 2 The effect of active alkali and sulfidity loading on Kappa number and klason lignin of pulp

The average kappa numbers of pulp were 6.51-8.20. The highest value was on 17% of active alkali and 22% of sulfidity treatment, while the lowest value was on pulping condition with 22% of active alkali and sulfidity. The increase of sulfidity loading didnot significantly affects the kappa number reduction. It means that all cooking condition provided a good delignification activity in the materials. The increase of sulfidity concentration is expected more dominant than that of alkali influence to kappa number reduction. These results are in line with our previous result [15], but contradiction with the study of Rahmiati *et al.*[8] that the lignin removal efficiency occurred with the increase of sulfidity loading. In cooking process, sulfidity is also determined by chemical equilibrium; it is higher in closed cycle pulping and will be lower in open cycle process. Optimum sulfidity depends on several factors such as the type of biomass, alkali concentration, cooking temperature, and the final properties of expected pulp. Active alkali concentration has a negative effect on kappa number, but not in sulfidity.

Klason lignin is a function of kappa number of pulp, that a high kappa number reflects the high content of lignin remaining in the pulp. In this case, the pulping condition using 17% of active alkali and 22% of sulfidity gave the highest residual lignin, while the treatment with 22% of active alkali and sulfidity provided the lowest value (Fig.2). Compared to initial lignin content of Numbu bagasse, the highest and lowest of the lignin reduction were 96.76% and 95.73%, respectively. It means cooking condition used was relatively effective for dissolving/delignification of lignin polymer. Lignin which swells in a kraft pulping on bagasse chips is chemically broken down into the fragments of hydroxyl (OH-) and hydrosulfide (SH-) ions in liquid chemical pulping. The lignin fragments then dissolved in the form of phenolate or carboxylate ions [18].

3.2.4 Delignification Selectivity

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

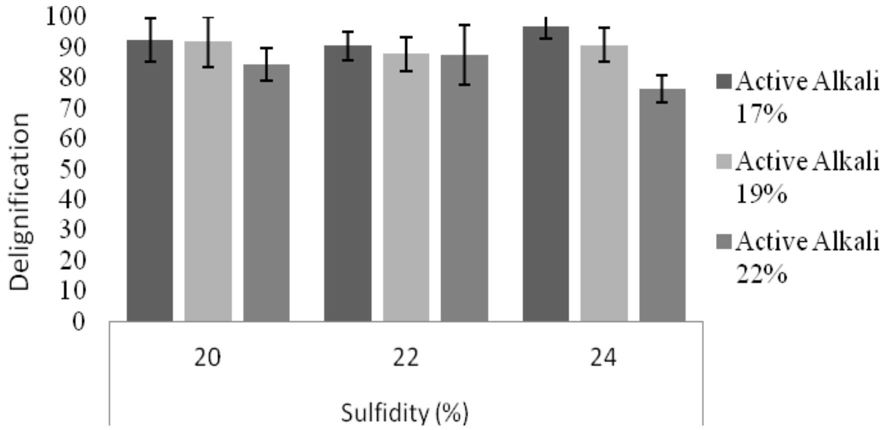

Figure 4 The efect of active alkali and sulfidity laoding on delignification selectivity of pulp

Fig 4 showed that delignification selectivity value ranges from 76.29-96.66, while the highest selectivity delignification ratio is on the pulping condition using 17% of active alkali and 24% of sulfidity and the lowest selectivity delignification ratio is utilization of active alkali of 22% and 24% of sulfidity. All treatments showed high values on this parameter which means that lignin degradation activity is higher than that of carbohydrate (cellulose and hemicellulose) degradation activity hence this kraft pulping condition is suitable for converting Numbu-bagasse chips into pulp.

3.2.5 Physical Properties of Pulp Sheet

In general, the pulping condition produced pulp properties with lower tear index than unbleached kraft and did not meet the requirement of burst index for unbleached Kraft pulp from softwood, except treatment using active alkali of 19% and sulfidity of 22%. The increasing active alkali tends to decrease the burst index, except on treatment using 20% sulfidity. This result was in line with the previous study reported by Sukaton [19] that the increase active alkali had a negative effect to the paper sheet properties.

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

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

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

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

Pulping condition		Gramatur (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

Received ________, Revised _________, Accepted for publication __________

4 Conclusions

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

Acknowledgement

The author wishes to thank to SEAMEO BIOTROP through DIPA 2012 funding in supporting the research and to Fitria, M.FoodSc. for the english checking and Veni for technical assistance.

5 References

[1] Patil J.V., Chari, A.,Rao S.V., Mathur R.M., Vimelesh,B. & Lal Preeti, S., *High bio-mass Sorghum (Sorghum bicolor): an alternate raw material for pulp and paper making in India,IPPTA Journal* 23 (2): April-June 2011

[2] Kumar, D. S. & Marimuthu, P., *Sweet sorghum stalks-an alternate agro based raw material for paper making,Ippta Journal* 24 (3), 2012.

[3] Belayachi,L. & Delmas, M., *Sweet sorghum: a quality raw material for the manufacturing of chemical pulp*. Biomass and Bioenergy 8(6), pp.411-417,1995.

[4] Wu,X, Staggenborg, S., Propheter, J.L., Rooney, W.L., Yu, J., Wang, D.. *Features of sweet sorghum juice and their performance in ethanol fermentation*, Industrial Crops and Products 31(1), pp.164-170,2010.

[5] Sipos, B., Reezey, J., Somorai, Z., Kadar, Z., Dienes, D., Reezey, K.,*Sweet sorghum as feedstock for ethanol production: Enzymatic Hydrolysis of steam-pretreated bagasse*. Appl Biochem Biotechnol 153:151-162, 2009.

[6] Thanapimmetha, A., Vuttibuchon, K., Saisriyoot, M., Srinophakun, P., Chemical and microbial hydrolysis of sweet sorghum bagasse for ethanol production. World Renewable Energy Congress 2011, 8-13 May, Linkoping Sweden, 2011.

[7] Supriyanto, Iswanto, A.H., & Fatriasari, W., Production of liquid organic fertilizer, particle board and kraft paper derived from sweet sorghum, Research Proposal DIPA Biotrop, 2012

Received ________, Revised _________, Accepted for publication __________

[8] Rahmati, H., Navaee-Ardeh, S. & Aminian, H., *Influence of Sulfidity and Active Alkali Charge on the Properties of Pulp Produce from Eucalyptus Camaldulensis*. Journal of Plant Sciences, 2 (6), pp.600-606,2007.

[9] Agricultural Departement, *Vandecum Kehutanan Indonesia*, Balai Pejelidikan Kehutanan,Jakarta,1976.

[10] Syafii, W & Z.Siregar, I., *Sifat kimia and dimensi serat kayu mangium* (*Acacia mangium Willd) dari tiga provenans*, Jurnal Ilmu dan Teknologi Kayu Tropis 4(1), pp29-32, 2006.

[11] Iswanto, A.H., Supriyanto, & Fatriasari, W., *Pemanfaatan limbah batang sorghum sebagai bahan baku papan partikel*, Workshop on The Current Status and Challenges in Sorghum Development in Indonesia.Bogor,25-26 September 2012

[12] MacDonald, R.G. & Franklin, J. N., *Pulp and paper manufacture: The pulping of wood*, Vol. 1 (2nd ed.). McGraw-Hill Book Company, New York. Pp. 35,1969

[13] Casey, J.P.,*Pulp and paper chemistry and chemical technology*,Vol 1, 3rd ed.Interscience Publishers, Inc., New York,1980.

[14] LPHH, *Dimensi Serat Jenis Kayu di Indonesia*. Bogor, P3HH, 1976.

[15] Fatriasari,W. & L.Risanto. *Sifat pulp kraft kayu sengon (Paraserianthes falcataria L. Nilsen): perbedaan konsentrasi bahan pemasak dan proses bleaching*,Widya Riset 14(3),pp.589-597, 2011.

[16] Fengel, D. & Wegener, G.,*Chemistry, Ultrastructure, Reaction*. Walter de Gruyter, Berlin, 1989

[17] Sjostrom, E., *Wood Chemistry: Fundamentals and Applications*. 2nd ed., Academic Press, San Diego, USA, 1981.

[18] Smook, A.G., *Handbook for pulp and paper technologist*,2nd Ed.,Angus Wilde Publication Inc.Vancouver,163-185,1992.

[19] Sukaton, E., *Variasi proses pulping kraft dari jenis bambu petung (Dendrocalamus asper Backer) sebagai bahan baku pulp dan kertas*, Rimba Kalimantan 9(1),pp.21-24, 2004.

[20] Abubakar, S.M, Scott. G.M., Klungness, J.H., *Fiber fractionation as a method of improving handsheet properties after repeated recycling*, TAPPI J 78(5),pp.123-136,1995.

[21] Hubbe, M.A. & Heitmann J.J., *Review of factors affecting the release of water from cellulosic fibers during paper manufacture*. Bioresources 2(3),pp.500-523,2007.

[22] Haygreen, J.G. & Bowyer J.L., *Hasil Hutan dan Ilmu Kayu: Suatu pengantar*,Terjemahan.Gajah Mada University Press, Yogyakarta,1996.

[23] Fuadi, A.M., Sulistya, H., *Pemutihan pulp dengan hidrogen peroksida*. *Reaktor* 12(2):123-128, 2008.