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Bamboo as raw materials for dissolving pulp with environmental friendly technology for rayon fiber

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Abstract

Dissolving pulp raw material for rayon in Indonesia is wood. The limited availability of wood, non wood is available in large numbers such as bamboo. Bamboo fibre has long fibre. A study for making of dissolving pulp of four types of bamboo such as Apus (*Gigantochloa apus*), Petung (*Dendrocalamus asper*), Mayan (*Gigantochloa robusta*) and Sembilang (*Dendrocalamus giganteus*). The pulping process is Pre-hydrolysed-Kraft and bleaching of pulp with environmental friendly technology (Elemental Chlorine Free and enzyme). Pulp bleaching yield between 94-97% is still high. Cellulose content bamboo dissolving pulp is higher than requirements Indonesian standard specification SNI (> 94%).

Keywords: wood, bamboo; dissolving pulp; rayon; environmental friendly technology

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1. Introduction

Wood species have been the primary raw materials for producing cellulose pulp; in fact 90-95% of all pulp has been obtained from such materials. In fact, the use of wood as a pulping raw material has severely compromised supplies and led to massive deforestation and replanting, and hence to an ecological imbalance[1].

Some efforts at the national and international levels are ongoing to find suitable substitutes for wood fibers, which are commonly called non-woods. Some of these non-woods are already used for papermaking, accounting for about 10 percent of the world's pulp production[2].

Currently the demand for dissolving pulp as raw material for the textile rayon fiber increased, due to cotton as a textile material is still imported. Rayon fiber has properties almost the same as cotton. Industrial raw materials dissolving pulp for rayon in Indonesia is the type of long fiber wood such as *Pinus merkusii* or short fiber wood such as *Eucalyptus* sp. The limited availability of wood and have a lot of problems related to environmental issues. The non-wood raw material alternative has several options and is available in large numbers, such as bamboo (long fibre) with diverse kinds.

In this context, bamboo appears as an alternative source for pulp and paper industry, particularly in the tropical areas of the world. Bamboo is the vernacular orcommon term for members of a particular taxonomic group of large

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woody grasses. Bamboos encompass 1250 species within 75 genera, most of which are relatively fast-growing, attaining stand maturity within five years, but flowering infrequently[3]. As an industrial raw material, bamboo has been used to produce both cellulosic fibers for paper and starch granules for saccharification and production or ethanol. In general, the α-cellulose content in bamboo is 40 to 50%, which is comparable with the reported α-cellulose contents of softwoods (40 to 52%) and hardwoods (38 to 56%)[4]. Undoubtedly, bamboo is a potential alternative source of raw material for dissolving pulp production because of long fibre.

Dissolving pulps require a high degree of purity used for production of cellulose derivatives such as cellulose acetate, viscose rayon, and carboxy methylcellulose, among many others. The overall fiber line yield for dissolving pulp production rarely exceeds 30 to 35%, the pulps contain a high α-cellulose content (95 to 98%) and relatively low hemicelluloses (1 to 10%) and lignin (<0.05%) contents[5]. Dissolving pulps typically are produced from cotton linters (soda pulping) and from wood via the pre-hydrolysis Kraft and acid sulphite pulping processes[6].

This study aimed at making of rayon pulp (dissolving pulp) of four species of bamboo such as Apus (*Gigantochloa apus*), Petung (*Dendrocalamus asper*), Mayan (*Gigantochloa robusta*) and Sembilang (*Dendrocalamus giganteus)* by the pre-hydrolysis-Kraft process and bleaching of pulp with environmental friendly technology (Elemental Chlorine Free and enzyme). The results are compared with Indonesian standard specification for dissolving pulp (SNI 0938:2010, Pulp Rayon).

2. Method

The experiments include raw material preparation, pre-hydrolyzed, kraft pulping, ECF (Elemental Chlorine Free) bleaching, testing of brightness, and dissolving pulp characteristics.

Raw material for the experiment in the form of bamboo Culmconsists of four species of bamboo such as Apus (*Gigantochloaapus*), Petung (*Dendrocalamus asper*), Mayan (*Gigantochloa robusta*) and Sembilang (*Dendrocalamus giganteus*) from PT. Wahana Sekar Agro, Bogor. The bamboo culm were chipped and dried in an open air to reach about homogeneous moisture content.

Fiber morphology was analyzed, includes fiber length (maximum, minimum and average), cell wall thickness and its derivatives (Runkel ratio, flexibility). Fiber morphology was determined in accordance with the Indonesian National Standard (SNI).

Chemical analysis of bamboo samples were conducted in accordance with SNI; holocellulose, α-cellulose, lignin, pentosan, ash, DCM extractives, solubility in cold and hot water, as well as in 1% NaOH.

The chips were pulping by the pre-hydrolyzed - Kraft process in laboratory scale. The pulping trials were carried out in a rotary digester with indirect electrical heating. Pulping conditions to make bamboo dissolving pulp arepre-hydrolyzed acidwith) 0.2%-0.4%; cooking with active alkali 20%-22%; sulfidity 30%-32%; H-factor 1500-1600; temperature165 °C; chips to liquor ratio1: 5. The cooked chips were washed with water and defibered at 2.5% consistency with a propeller mixer. After washing, the pulp was refined, pressed and shredded. Total pulp yieldwere measured. Kappa number of yield pulp was determined according to SNI 0494-2008.

Pulp bleaching was carried using chlorine dioxide (ClO_2), known as 5 stages Elemental Chlorine Free (ECF) bleaching process; $ODoEoD_1D_2$ stage (oxygen delignification, early stage chlorine dioxide, extraction, 1st stage chlorine dioxide, extraction, 2nd stage chlorine dioxide)and $XODoEoD_1$stage (Xylanase, Oxygen delignification, early stage Chlorine dioxide, Extraction, 1st stage Chlorine dioxide). Bleached pulp was washed with water up to neutral pH. Pulp bleaching condition is presented in Table 1.

Dissolving pulp properties tested in accordance with the specifications of regular rayon pulp, parameters was tested alpha cellulose content, alkali solubility (10% and 18% NaOH), extractive (dichloromethane), ash, acid in soluble ash, viscosity, intrinsic viscosity and brightness.The content of alpha cellulose pulp was tested based on SNI 0444, alkali Solubility is tested based on SNI ISO 692, extractive tested accordance with SNI 7197, ash content tested according to SNI 7460.

Table1.Pulp Bleaching Using $ODoEoD_1D_2$ Stage and $XODoEoD_1$ Stage

Parameter	X	O	D_o	Eo	D_1	D_2	sulfuric acid
ClO_2, %	-	-	0.22 KN	-	1	0.5	-
O_2, psig	-	87	-	29	-	-	-
NaOH, %	-	1.5	-	1	-	-	-
H_2SO_4	-	-	end pH	-	-	-	0,5
Consistency, %	10	10	10	10	10	10	10
Temperature, °C	50	95	70	80	75	75	room
Time, minute	30	60	60	75	180	180	5
End pH	-	10.5-10.8	2.5-3.5	11.5-12.0	4.0	3.5	3
Xylanase, kg/ton	1	-	-	-	-	-	-

The acid in soluble ash tested according to SNI ISO 776, pulp viscosity was tested based on SNI 0936 and SCAN-CM 15, Viscosity in CED solution. Brightness tested in accordance with SNI ISO 2470.

3. Results and Discussion

3.1 Fiber Morphology of Bamboo

The bamboo fiber length was showed in Table 2. The table shows the value of morphology of four type of bamboo fiber such as Apus, Mayan, Petung and Sembilang based on the assessment criteria for wood pulp and paper raw materials[7]. The fiber length four types of bamboo belong to the long fibers class, range from 2.34 to 3.24 mm. The long fiber of the wood or non wood pulp has produced a high strength and high cellulose content.

Apus bamboo diameter and fiber wall thickness is smaller than Petung, Mayan and Sembilang bamboo. Thin-walled fiber easily refined to produce pulp and paper sheet are more solid and better bursting strength and reduces the refining power to fibrillation compared with the thick-walled fiber. Conversely, thick-walled fiber will produce sheet that has high tear strength, but low tensile strength[8].

In addition to fiber length, fiber requirements for pulp raw materials also determined by the fiber dimension derived value. Fiber dimension derived value includes Runkel Ratio, Muhlstep Ratio, Flexibility Ratio, and Coefficient of rigidity.The four type of bamboo Runkel ratio in the range of 1.07 to 1.24. Runkel ratio is the ratio of cell wall thickness to lumen diameter. Fibers with Runkel ratio value less than or equal to 1 can be used as a pulp raw material. Four bamboo shave a thickness fiber wall but wide lumen diameter, so it will be easily to refining and easily to fibrillation.

Coefficient rigidity value of four bamboo are similar. Value of coefficient of rigidity is the cell wall thickness ratio of the fiber diameter.This comparison showed a negative correlation to the length of break strength (tensile strength), meaning that the higherthe coefficient, the lower stiffness of the tensile strength of the paper[7].

Table 2. Results of fiber morphology 4 type of bamboo

No.	Parameter	Unit	Apus	Sembilang	Petung	Mayan
1.	Fiber length, max	mm	4.89	4.55	6.62	3.39
2.	Fiber length, min	mm	1.20	1.42	1.65	1.03
3.	Average fiber length (L)	mm	2.34	2.78	3.24	1.90
4.	Outer Diameter (D)	µm	14.54	21.34	21.30	22.22
5.	Lumen Diameter (l)	µm	6.12	10.31	9.77	9.91
6.	Wall thickness (W)	µm	4.21	5.52	5.77	6.16
7.	Runkel ratio (2W/l)		1.18	1.07	1.18	1.24
8.	Felting ratio (L/D)x1000		160.94	130.27	152.11	85.51
9.	Rigidity (W/D)		0.29	0.26	0.27	0.28
10.	Flexibility (l/D)		0.42	0.48	0.46	0.45

3.2 Chemical Composition of Bamboo

Chemical composition of four type bamboo is presented in Table 3. It is shown that α-cellulose of four type bamboo are in the range of 44.36 – 48.60%. The higher α-cellulose content is obtained from Petung (individual bamboo). The values are above the average α-cellulose content of softwood (45 ± 2%). Wood or non-wood of high content α-cellulose is expected to produce high pulp yield. Purity cellulose is often expressed through the parameter α-cellulose. The α-cellulose is important in pulp industry because of its high degree of polymerization.

Table 3.Chemical composition of four type of bamboos

No.	Parameter (%)	Apus	Sembilang	Petung	Mayan
1.	Ash	6.09	3.70	2.13	1.66
2.	Extractive (Ethanol-Benzene)	4.89	4.51	3.41	8.38
3.	Lignin	22.41	23.85	25.27	23.86
4.	Holocellulose	63.23	65.96	68.25	56.81
5.	α-Cellulose	47.56	46.88	48.60	44.36
6.	Pentosan	19.34	21.61	20.87	18.37
7.	Cold water solubility	10.89	8.73	7.05	13.06
8.	Hot water solubility	12.67	10.57	8.02	15.01
9.	1% NaOH Solution Solubility	29.87	28.19	22.12	28.45

The holocellulose content of four type of bamboos ranged between 56.81 – 68.25%, under the terms of the properties of wood as raw material for pulp[9], holocellulose content of four type bamboo because over 65%. Holocellulose content statedamount ofpolysaccharidesarecompoundscomposedofcelluloseandhemicelluloses. Holocellulose withhighcontent canproducepulpwithhighyield. But for dissolving pulp, hemicellulose has to small in pulp, because hemicelluloseis alow molecular weightpolysaccharidespresent inthe cell. Ligninis the gluebetween thefibre, has arigidnature. Residual lignin in the pulp has adverse effects on color and physical properties of pulp[10].Highlignin contentwill consume pulping and bleaching chemicalsalso high, andthe fibrewill be difficult tobe described. Under the terms of the properties of wood as raw material for pulp[9],four type of bamboois quite high as it has a lignin content of between 22.41-25.27 %.

Extractive substances beyond fiber components that are not an integral part of the cell wall, the high content of extractives will also complicate the penetration of pulping liquor. Mayan bamboohas the higher extractive content than other bamboo. Under the terms of the properties of wood as raw material for pulp[9], high contents of extractives pulp (pitch) which will affect less well on the quality of the pulp, because the pitch will consume more pulping and bleaching chemicals, interfere in the production of dissolving pulp, resulting in a lower brightness value.

3.3 Pulping Results

Pulping of bamboo conducted in H-factor condition 1500-1600. Pulping Result at H-factor 1600 showed in Figure1. Result showed that Sembilang bamboo more easily to cook than Petung, because lignin content of Sembilang lowers than Petung. Sembilang reach Kappa number target (below 13) at H-factor 1600.

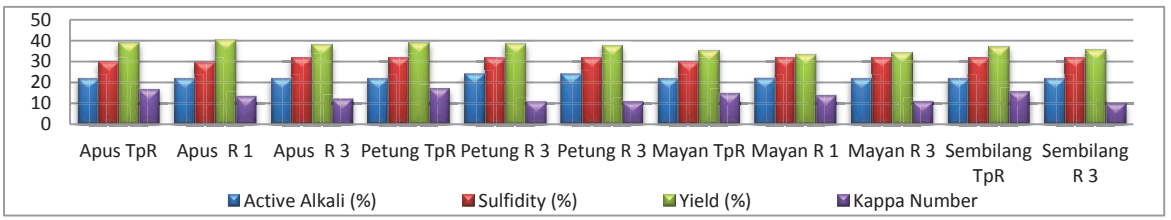

Fig. 1. Pulping result of four type of bamboo

The pulping with H-factor1500 produces pulp with Kappa number above 18, so it does not meet the target. Pulp yield still high with yield range above 33%.

Optimum pulping condition to make bamboo dissolving pulp is pre-hydrolyzed acid with 0.4%; and cooking with active alkali 2%; sulfidity 32%; H-factor1600; temperature165 °C; chips to liquor ratio1: 5.

3.4 Pulp Bleaching Result

Bleaching of four type of bamboo ranged between 94.82–96.79%, bleaching yield of pulp still high (above 95%). Pulp was conducted of their Kappa number in the range of 10.18-12.37. In general, the dissolving pulp industry in Indonesia, producing pulp with a target kappa number 10-13. Bleaching results ($ODoEoD_1D_2$) of the yield calculated to wood, the pulp yield are in the range listed in Figure 2 shows that the yield are 32.58%-36.96%. Brightness of pulp that meets the requirements of SNI 88% ISO are Sembilang bamboo pulp.

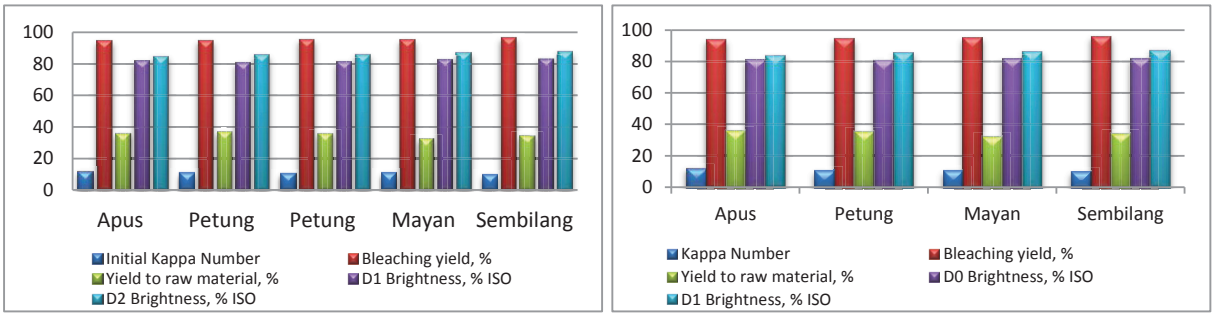

Fig. 2. Bleaching result $ODoEoD_1D_2$(left) and XOD_0EoD_1 (right) of four type of bamboos

Four types of bamboos produce dissolving pulp with a yield in the range 94-96% for XOD_0EoD_1 stage and still quite high above 94%, but lower yield than $ODoEoD_1D_2$.The brightness value four types of bamboo dissolving pulp only Sembilang higher than other bamboo close to the value of SNI Brightness value upper 88% ISO, in the range of 84.40 to 88.12% ISO. To increase dissolving pulp brightness can be achieved by increasing the dose of xylanase (optimum). Bleaching sequence which suitable to produce bamboo dissolving pulp and meet SNI brightness requirements is $ODoEoD_1D_2$ sequence.

Tabel 4. Bamboo dissolving pulp characteristic three typesof bamboo

No	Parameter	Unit	SNI 0938:2010 Pulp Rayon	Mayan ($OD_0EoD_1D_2$)	Sembilang ($OD_0EoD_1D_2$)	Sembilang (XOD_0EoD_1)
1.	Alpha cellulose	%	min. 94	96.57	97.49	96.61
2.	S10	%	maks. 7.9	4.69	4.29	5.04
3.	S18	%	maks. 4.9	1.29	1.20	1.32
4.	Acid insoluble ash	mg/kg	maks. 80	120	91	100
5.	Extractive (dichloromethane)	%	maks. 0.2	0.06	0.09	0.09
6.	Ash	%	maks. 0.15	0.08	0.08	0.08
7.	Instrinsic viscosity	mL/g	min. 400	556	567	560
8.	CED viscosity	cP	min. 6.2	16.21	17.03	15.97
9.	Brightness	% ISO	min. 88	87.26	88.12	87.63

3.5 Dissolving Pulp Characteristics

Ash contents should be lowering undetectable in the dissolving pulp. Ash content of four types of bamboo is lower than the standard requirements, but insoluble ash (silica and silicate) content still very high. Three types of bamboo dissolving pulp characteristics can meet the SNI 0938:2010: specification of rayon pulp from wood except acid in soluble ash content. It is necessary tothink about ways to eliminate them, because it will cause the scale in the digester and clogging the recovery pipes. Acid insoluble ash can reduce by decortications the raw material, and washing - cleaning system in pulp mill. Results show that the extractive content bamboo dissolving pulp can meet with SNI requirement.Alkali solubility in18% NaOH solution (S18) and alkali solubility in 10% NaOH solution (S10) is lower than SNI requirement. Dissolving pulp viscosity (Cupri-ethylenediamine) is very high compare to wood dissolving pulp about 450-500, which means that cellulose is not much degraded and still long chain.

Conclusion

Characteristic of the four types of bamboo is solving pulp (Apus, Mayan, Petung and Sembilang bamboo) is higher cellulose content more than 94% and the solubility of bamboo pulp in alkaline solution and extractive content is lower than SNI rayon pulp requirements. Bamboo that selected to be suitable dissolving pulp raw material is Sembilang bamboo and Mayan bamboo consecutively. Optimum pulping condition to make bamboo dissolving pulp are pre-hydrolyzed acid with 0.4%; and cooking with active alkali22%; sulfidity32%; H-factor1600; temperature165 °C; chips to liquor ratio1: 5 and pulp bleaching with ($OD_0EoD_1D_2$)sequence.

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