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Manufacturing of high brightness dissolving pulp from sansevieria-trifasciata fiber by effective sequences processes

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Abstract

The need of dissolving pulp (DP) for rayon fiber production is increasing rapidly in recent years. Sustainable sources of DP raw materials and an effective manufacturing process are urgently required. This study aims to manufacture dissolving pulp (DP) with high brightness from Sansevieria-trifasciata (ST) fiber through the pre-hydrolysis, soda-Anthraquinone (Soda-AQ) cooking, and chlorine-free bleaching processes. The cellulose content, kappa number, pulp yield, and viscosity were analyzed. The results showed that the α-cellulose content in ST raw material (39.43%) was relatively similar to the α-cellulose content in Acacia pulping kraft (39.2%). Furthermore, the variations in pre-hydrolysis time affected the Kappa number, pulp yield, and viscosity. The DP obtained by the elementary chlorine-free (ECF) bleaching process had a viscosity of 9.3 cP, α-cellulose content of 97.7%, and the brightness of 90.1% which was higher than the ISO standard of pulp brightness. The high DP brightness obtained from this unique combination of pre-hydrolysis, soda-AQ cooking and chlorine-free bleaching sequences has great potential for further development, as it can be used in viscose rayon staple fibers production.

Keywords: brightness; chlorine-free; dissolving pulp; sansevieria-trifasciata; pre-hydrolysis

1. Introduction

The development of the rayon fiber industry is increasing every year. It is because the world's demand on rayon fiber is very high [1,2]. Rayon can be made from cotton, dissolving pulp (DP) or other viscose fibers [1–3]. In particular, DP as a raw material for rayon production shows its own special features due to its good properties and is preferred by consumers compared to other sources of rayon raw materials [4].

Wood or non-wood containing high cellulose can be used as a raw material for making DP [1,4]. Sansevieria trifasciata (ST) as non-wood materials is predicted to be a strong candidate for DP raw material with many advantages [2]. It contains cellulose > 50% with a fiber diameter ranging from 112-128 µm with an average of 120 µm [2,3]. The mechanical and physical characteristics, namely water absorption of 56%, the tensile strength of 268 MPa, and the elasticity modulus of 15 Gpa imply that ST fiber has a high prospect as a raw material for the manufacturing of DP [5,6]. This tropical plant is easy to grow, survives in a wide temperature and light range, as well as useful for various purposes, such as raw material for pulp, antiseptic, adsorbent, etc. It also has high economic value and is one of the most exported commodities [3,7].

The production of DP from non-wood materials can be carried out in three stages, namely, pre-hydrolysis, cooking with soda or kraft processes, and elementary chlorine-free (ECF) or total chlorine-free bleaching (TCF) [8,9]. Pre-hydrolysis is an important step in reducing hemicellulose content and helps in the separation of lignin from raw materials. Compared to the widely used Kraft process, Soda-Anthraquinone (soda-AQ) cooking is considered more environmentally friendly because it does not produce toxic gases such as hydrogen sulfide and sulfur dioxide, and is suitable for non-wood materials. Anthraquinone (AQ) acts as a redox catalyst during the soda process, by lowering the aldehyde end group of carbohydrates, forming carboxylic acids and inhibiting alkaline depolymerization, thereby increasing pulp yield. Aklilu et al. [10] compared the Kraft and Soda-AQ processes for pulping oak trees. It was found that the pulp from the Soda-AQ process had a lower kappa number, higher brightness, and slightly lower viscosity compared to the Kraft process [10].

Investigations on bamboo as raw material for DP using environmentally friendly technology found that the cellulose content being more than 94%, and the solubility in alkaline solution along with the extractive content is lower than the requirements of SNI rayon pulp [11,12]. In a previous study,

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the manufacture and characterization of long fiber DP from bamboo thorns was carried out using the pre-hydrolysis kraft cooking process and bleaching in two sequences, namely chlorine dioxide-extraction chlorine dioxide-chlorine dioxide (DoED1D2) and chlorine dioxide-extraction with peroxide-chlorine dioxide-chlorine dioxide (DoEpD1D2) [11,13,14]. Its chemical composition is comparable to Eucalyptus and Pinus species, except for the ash content and 1% NaOH solubility. The dissolving yield of thorn bamboo pulp ranged from 37.97 - 40.76%, α-cellulose content of 94.88 - 98.67% and viscosity of 16.43 - 25.75 cP. Decorticated bamboo with bleaching sequence of DoEpD1D2 produced the most superior DP with the highest degree of brightness and highest α-cellulose of 89.61 % ISO and 98.67%, respectively [11].

In this work, the production of DP from ST materials was performed in three stages, namely pre-hydrolysis, cooking, and bleaching. Effects of water pre-hydrolysis, Soda-AQ cooking and ECF and TCF bleaching sequences on the Kappa number, pulp yield, viscosity, the content of a-cellulose and brightness of ST-based DP were studied. For comparison purposes, cooking with Kraft-Anthraquinone (Kraft-AQ) was also conducted. ST plants had a dark green color which caused the pulp produced by cooking to have a brownish yellow with a brightness value of 40%. This value then reached 90.1% after a pulp washing (with water and hexane) and bleaching processes. To the best our knowledge, this unique combination of processes in the ST-based DP production has not been found, and is very promising route for high brightness ST-based DP production.

2. Materials and Method

The ST materials were obtained from a yard in Panam, Pekanbaru, Riau, Indonesia. They were cut into 0.5–1 cm fiber fragment and dried to a 6–10% moisture content. The ash content was determined by incinerating at 575ºC for 4 h according to the TAPPI Test Method: T211 om-12 [9,15]. For the extractive analysis, the materials were milled with a Wiley mill and sieved to retain particles of 40–80 mesh in size, then kept at room temperature and air-dried. Furthermore, the extractives were determined by extraction with acetone and n-hexane according to the TAPPI Test Method: T204 cm-07 [9,16].

The content of acid-insoluble lignin (Klason lignin) of the ST raw materials was determined as follows: the prepared sample (0.5 g, as oven-dried weight) was primarily hydrolyzed with 72.5% sulfuric acid for 2.5 h and further hydrolyzed with 4.0% sulfuric acid at 121ºC for 1 h. The sample was then filtered to obtain the residue and filtrate with a glass filter (1 GP 16). The weight of the residue was measured as acid-insoluble lignin. The amount of acid-soluble lignin was determined according to UV spectrophotometry at a wavelength of 205 nm (TAPPI Test: T222 om-11) [9].

2.1. Pre-hydrolysis and cooking

ST materials (35 g, as oven-dried weight) were placed in a 300 mL steel reactor and subjected to pre-hydrolysis with 245 mL of distilled water for 90–180 min at 150ºC [5,9]. After pre-hydrolysis, a part (140 mL) of the pre-hydrolysis liquor (PHL) was removed. The liquor-to-solid ratio of pre-hydrolysis was 7 mL/g for the treatment of PHL removal. On the other hand, ST materials (35 g) were subjected to pre-hydrolysis with 105 mL of distilled water for 90–180 min at 150 ºC [9]. After pre-hydrolysis, any PHL was not removed. The liquor-to-solid ratio of pre-hydrolysis was 3 mL/g for the treatment of PHL non-removal. After pre-hydrolysis, the wet solid residue was further subjected to soda-AQ cooking for 180 min at 160ºC with 15 and 20% active alkali (AA) dosages by adding 140 mL of fresh alkaline cooking liquor [9]. The dosage and liquor-to-solid ratios of AQ (SAQ: 1,4-dihydro-9,10-dihydroxy anthracene sodium salt, supplied by Kawasaki Kasei Chemicals Ltd.) were 0.1% and 7.5%, respectively. Wet pulp was subjected to washing with water several times, then it was soaked in technical hexane for 5 hours, separated from hexane, washed with water, and then bleached. Next, air-dried pulp sheets were prepared to measure the pulp yield after cooking.

2.2. Bleaching sequences and conditions

The following sequences and conditions of bleaching were chlorine dioxide-extraction with peroxide-chlorine dioxide (D0–Ep–D1). For ECF sequences, pre-hydrolysis soda-AQ pulp (10 g, as oven-dried weight) was treated in a bag made of polyvinylidene chloride sheets with ClO_2 at a pulp consistency (PC) of 10%. After washing, the pulp was treated in a polyethylene bag with NaOH and H_2O_2, washed again, and treated in the polyvinylidene chloride bag with ClO_2. Pre-hydrolysis soda-AQ pulp (10 g, as oven-dried weight) was oxygen (O) bleached at a PC of 30% for the oxygen-peroxymonosulfuric acid-extraction with peroxide-peroxymonosulfuric acid-extraction (O–Psa–Ep–Psa–E) TCF sequence. According to the previous procedure [17], peroxymonosulfuric acid (Psa) was synthesized by dropping 95% sulfuric acid (Wako Pure Chemical Industries, Ltd.) into a 45% hydrogen peroxide aqueous solution (Mitsubishi Gas Chemical Company, Inc.) at 70ºC. A target amount of Psa and a small amount of NaOH aqueous solution for adjusting to pH 3.0 were added to the pulp suspension at a PC of 10% in a polyethylene bag.

2.3. Evaluation of pulp qualities

The acid-insoluble and acid-soluble lignin contents as well as the carbohydrate composition were determined according to the methods mentioned previously. Kappa number, viscosity, brightness, and a-cellulose were determined using the TAPPI Test Methods: T236 om-13 [9], T230 om-13 [9], T452 om-08 [18], and T203 cm-09 [19], respectively. The brightness (ISO) was measured using a Tokyo-Denshoku Digital Color Meter Model TC-1500 SX.

3. Results and Discussions

The chemical composition of ST materials is presented in table 1 The wood of *Acacia mangium* and pulp from Acacia pre-hydrolysis kraft pulping were used as references. The total lignin (acid-insoluble and acid-soluble) and the content of cellulose for ST raw material are 15.04 % and 58.10 %, respectively (table 1). ST has high lignin content, but it was reduced by 1% after the Soda-AQ and Kraft-AQ pre-

hydrolysis processes were carried out, with values of 0.54% and 0.82%, respectively (table 1). A previous study reported that the extractive substance of the mother-in-law's tongue (Sansevieria trifasciata Prain), which is soluble in ethanol at 12.53% [20]. This is not significantly different from the result obtained in this study (12.49%). The contents of extractives for ST raw material are higher than the other lignocellulosic materials such as Acacia. Acacia mangium wild [21] and Acacia mearnsii wood [22,23] as plantation hardwoods used for paper production.

The alcohol-soluble extractive substances in ST is higher (12.49%) than in Acacia mangium (6.67%). High content of extractives, especially those soluble in alcohol-benzene, can hinder the pulp processing because the extractive substances will react with the cooking solution, causing a decrease in pulp yield. Therefore, the pulp yield of ST treated with Pre-hydrolysis Kraft-AQ Pulps is lower (33.81%) compared to the pulp yield of Acacia mearnsii Pre-hydrolysis kraft pulping (45.2%) (table 1).

Table 1. Chemical Composition of ST material and pulp

	Kappa Number	Yield (%)	Total Lignin (insoluble + soluble in acid), %
Raw material of Sansevieria trifasciata (ST)	-	-	15.04
Raw material of Acacia mangium wild [22]	-	-	29.81
Pre-hydrolysis Soda-AQ Pulp[a]	3.46	37.54	0,54
Pre-hydrolysis Kraft-AQ Pulp[b]	3.86	33.81	0.82
Acacia Prehydolysis kraft pulping	13.2	45.2	1.1

[a] Cooking temperature and time: 160ºC and 180 min, active alkali dosage 15%
[b] Prehydolysis temperature and time: 160ºC and 180 min
[c] Acacia mangium wild: Ref. [22]
[d] Acacia mearnsii: Ref. [24]

The ST materials have a relatively high ash content (7.65%) because they contain inorganic and mineral compounds. According to previous reports, the main elements in the ST ash are potassium, calcium, and silica [20,25]. The ash content decrease after cooking from 7.64% of the ST material to 0.75% of the pre-hydrolysis soda-AQ pulp and 0.50% of the pre-hydrolysis Kraft-AQ pulp. Because most of the ash content of ST leaves is soluble in water and silicate compounds are insoluble in both water and acid.

Interestingly, the contents of -cellulose for ST raw material (39.43%) are the same as the contents of -cellulose in Acacia Pre-hydrolysis kraft pulping (39.2%). It can be concluded that ST is a high-potential resource as a raw material for the manufacture of DP, revealing a high content of total cellulose of 58.10%, not much different from that of sugarcane bagasse (62.0%) and Acacia mearnsii (58.6%) for paper and paperboard [24]. The key advantage of ST materials as a potential resource for DP production in Indonesia is that this plant is very easy to grow and cultivate, and it does not require special care [3,18]. In addition, Sansevieria, belonging to the family Agavaceae, is one of the ornamental plants [26]. Its unique and beautiful appearance has many benefits, including as a textile fiber, absorbing toxins, odors, and CO_2 [19], even in an article mentioning that Sansevieria leaf extract can inhibit the growth of cancer cells [17].

3.1. Application of pre-hydrolysis and cooking to ST materials

The yields of DPs from wood (given by acid sulfite, multistage sulfite, and pre-hydrolysis kraft methods) are generally between 35 and 40% [9]. In this research, the effects of pre-hydrolysis treatments of ST materials are thoroughly evaluated based on the delignification of the Soda-AQ and Kraft-AQ cooking processes.

As shown in table 1, the kappa number and the pulp yield of ST pre-hydrolysis Soda-AQ pulp are 3.46 and 37.54 %, respectively, which are significantly higher than those Kraft-AQ pulps (3.86 and 33.81 %, respectively). Differences in kappa numbers and yields between the two pulps cannot be explained by variations in the amount of lignin and carbohydrates before and after the pre-hydrolysis.

3.2. Effect of pre-hydrolysis time

Figure 1 and 2 show the effect of pre-hydrolysis time and alkaline activities (AA) on the pulp yield. The pre-hydrolysis treatment is aimed at studying delignification because it is predicted that some hemicellulose can dissolve during the pre-hydrolysis process. Previous studies [27] stated that the pre-hydrolysis with water might diminish the linkages between lignin and carbohydrates, while the dissolution of hemicelluloses will also create some holes in the cell walls of the material, thereby culminating in an efficient treatment in the subsequent process.

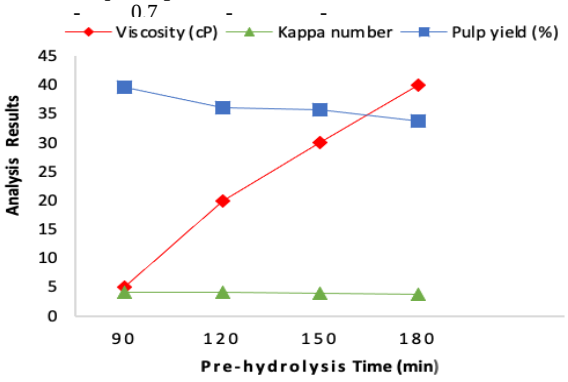

Fig. 1. Effects of pre-hydrolysis (150ºC) AA (15%) on Kraft-anthraquinone (AQ) cooking of ST (160ºC)

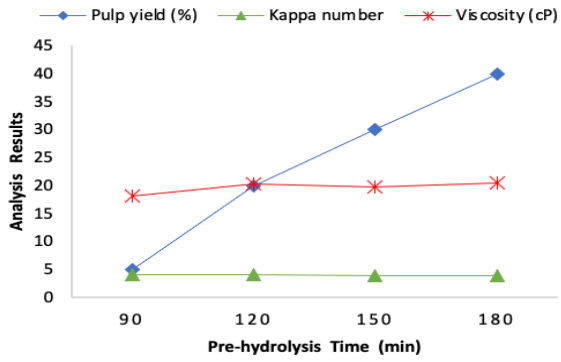

Fig. 2. Effects of pre-hydrolysis (150ºC) and AA (20%) on Kraft-anthraquinone (AQ) cooking of ST (160ºC)

There is a tendency that the longer the pre-hydrolysis time, the lower the kappa number (figure 1 and 2, table 2). Based on the kappa number data, all treatments produced DP which had

a kappa number 10, both in the pre-hydrolysis treatment with kraft-AQ cooking (figure 1 and 2) and with the soda-AQ pre-hydrolysis treatment (table 2). Pre-hydrolysis time is increasing the dose of active alkali (AA), which affects the kappa number and yield of the resulting pulp, but the viscosity is increasing.

The maximum kappa number and yield pulp under conditions for making DP from ST materials with Kraft-AQ pre-hydrolysis are pre-hydrolysis for 90 minutes with a dose of 20% AA, namely 4.76 and 42.54%, respectively. Meanwhile, the pre-hydrolysis of soda-AQ is pre-hydrolyzed for 90 min with a dose of 15% AA, namely 4.73 and 43.69, respectively. Interestingly, the pre-hydrolysis conditions for 180 min followed by cooking soda-AQ with a dose of 15% AA produced pulp with the highest viscosity of 22.2 cP with a kappa of 3.46 and a pulp yield of 37.54%. The increase in AA dose is shown to result in a decrease in viscosity and a low kappa number with high viscosity which will provide advantages in the following bleaching steps.

Table 2. Effects of pre-hydrolysis and AA on Soda-anthraquinone (AQ) cooking of ST

Pre-hydrolysis time (min)[a]	Active alkali[b] (%)	Kappa number	Pulp yield (%)	Viscosity (cP[c])
90	15	4.73	43.69	18.8
120	15	4.15	41.02	21.8
150	15	3.88	39.12	21.1
180	15	3.46	37.54	22.2
90	20	5.04	42.03	19.1
120	20	3.96	41.69	20.2
150	20	3.80	39.42	19.6
180	20	3.32	36.85	21.4

[a]Pre-hydrolysis temperature: 150°C
[b]Kraft-AQ cooking temperature: 160°C
[c]Centipoise

3.3. Effect of bleaching ssequences

The bleaching sequence in both ECF and TCF affects the α-cellulose content, the viscosity, and brightness of the pulp (table 3). The pulp produced is in accordance with the Indonesian National Standard (SNI) [28]. The minimum level of DP for rayon is a viscosity of 6.2 cP, a 94% α-cellulose content, and an ISO brightness of 88% according to SNI. The pulp produced has a higher brightness level with a lower dose of ClO_2 according to SNI [28]. This indicates the potential for DP production from the ST materials by using a combination of pre-hydrolysis, cooking soda-AQ, and ECF.

Delignification by oxygen is the first stage in the TCF bleaching sequence, as it can delignify and increase pulp brightness without substantial reductions in pulp yield, viscosity, and α-cellulose. The target brightness of ISO 88% could be achieved for the TCF bleach sequence. The brightness levels above 88.3% ISO still indicate the potential for TCF bleaching applications for ST.

According to a previous study, TCF bleaching was able to reduce environmental impacts compared to ECF bleaching [8]. TCF bleaching involves the use of hydrogen peroxide (Ep-P), oxygen (O), ozone (Z), and peroxymonosulfuric acid (Psa) in its stages to replace chlorine [8]. Compared between ECF and TCF bleaching after the soda-AQ process for empty oil palm fruit bunches, where the pulp brightness level was 81.6% for ECF and 90.7% for the TCF process [9]. greater than 6.2 cP, 94% minimum α-cellulose content, and 0.15% maximum ash content [8].

Table 3. Viscosity, brightness, and α-cellulose of bleached pulp

Bleaching sequence	Viscosity (cP)	Brightness (% ISO[a])	α-Cellulose (%)
ECF bleaching sequence:			
D0–Ep–D1	9.3	90.1	97.7
Psa–D0–Ep–D1	8.7	89.8	97.4
TCF bleaching sequence:			
O–Psa–Ep–Psa–E	7.9	88.3	95.9
Bleaching conditions:			
D0 Chlorine dioxide	ClO_2 dosage: kappa factor 0.30 (2.9 %), 60 min, 70 °C, pH 3.4, PC[b]: 10 %		
Peroxymonosulfuric acid (Psa)	Psa dosage: 0.2 %, 60 min, 70 °C, pH 3.0, PC: 10 %		
Extraction with peroxide (Ep)	NaOH dosage: 1 %, H_2O_2 dosage: 1.4 %, 60 min, 70 °C, PC: 10 %		
D1&D2 Chlorine dioxide	ClO2 dosage: 0.5 %, 60 min, 70 _C, PC: 10 %		
O Oxygen	Oxygen pressure: 0.5 MPa, NaOH dosage: 1 %, 60 min, 115 °C, PC: 30%		
E Extraction	NaOH dosage: 1 %, 60 min, 70 °C, PC: 10 %		

[a]International Organization for Standardization
[b]Pulp consistency

Fig. 3. Figures of ST pulp with soda-AQ cooking: before bleaching and washed with water (a); after bleaching and washed with water (b); before bleaching and washed with water and hexane (c); after bleaching and washed with water and hexane (d)

Several studies used agro-industrial waste as a raw material for making DP. Andrade and Colodette [29] produced DP from bagasse waste using the soda process and ECF bleaching with oxygen (O), chlorine dioxide (D), alkaline extraction with hydrogen peroxide (Ep), chlorine dioxide (D), and alkaline hydrogen peroxide (P) or OD-Ep-DP [29]. The ISO pulp brightness obtained was 88.5%. Another

study used the same process using banana stems and obtained a pulp brightness level of 77.9% [30]. A brightness level of 89% was reported by Matin et al. [8] for jute stems and different bleaching stages (D0-Ep-D1-Ep-D1) [8,31]. Another study using bamboo as raw material obtained pulp brightness of 92% [32]. There are differences in the brightness level of the pulp (Fig 3). Pulp washed with water and hexane is brighter (d) than those washed only with water (b).

4. Conclusions

The variations in pre-hydrolysis time affected the kappa number, pulp yield, and DP viscosity. Soda-AQ and Kraft-AQ produced soluble pulp with pulp yields of 43.69% and 42.54%, respectively, and kappa numbers of 4.73 and 4.76 (10). Both DPs were consistent with the DP level for rayon of the SNI standard. A brightness level of 90.1% was higher than 88% of ISO brightness, which was obtained by an ECF bleaching sequence with adequate viscosity and a-cellulose values. The sequence of Psa-D0-Ep-D1 reached 89.8% ISO brightness, 8.7 cP viscosity, and 97.4% a-cellulose, which met the SNI for rayon.

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