The characteristics of thorny bamboo (*Bambusa blumeana*) for dissolving pulp

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Abstract. This study was aimed to examine the raw material characteristics of thorny bamboo (*Bambusa blumeana*) from two different origins. Thorny bamboo is one of the raw material for dissolving pulp (rayon pulp). The origins of the bamboos were Agam Regency (West Sumatra Province) (TB1) and Perawang City of Siak Regency (Riau Province) (TB2) that represented highland and lowland, respectively. Bamboos from the two origins were analyzed for their raw material characteristics consisted of growth, chemical contents, fiber dimension and dissolving pulp. The pulping process was carried out in steps as followed: pre-hydrolyzed, kraft pulping and pulp bleaching. The pre-hydrolysis techniques used acetic acid solution. The kraft condition was active alkali 25% and sulfidity 32%. Meanwhile, the bleaching was conducted in 4 stages. The analysis was done descriptively. Dissolving pulp requires high purity level of alpha-cellulose that would be attained by dissolving other components from the system. The results showed alpha-cellulose of thorny bamboo from Agam (TB1) and Perawang (TB2) were 51.28% and 36.90%, respectively. However, the fiber of TB2 was longer than that of TB1 that 3.22 and 2.62 mm, respectively. The yields pulp kraft of thorny bamboo TB1 and TB2 were 35.25% and 36.28%, respectively. The alpha-cellulose of the thorny bamboo met the standard for dissolving pulp but not the mineral and acid insoluble ash content.

1. Introduction

Bamboo fibers have similar characteristics with softwoods that both are classified as long fibers. This fact has made bamboo as a good material for pulp, paper and dissolving pulp. Fiber industry in Indonesia, however, mostly relies on the imported fiber material. Therefore the vast potential of bamboo thus becomes prospective material for the industry, considering Indonesia has a rich bamboo biodiversity. Indonesia has 157 species of the 10% of bamboo species in the world [1].

Bamboo grows well in both high- and lowland, e.g. thorny bamboo (*Bambusa blumeana*). We collected thorny bamboo from Agam Regency, West Sumatra Province (TB1) as the highland representative and from Perawang City, Siak Regency, Riau Province (TB2) as lowland thorny bamboo representative. The sampling was still limited though, having not represented the wet and dry land as this bamboo is also found in those type of environments.

Thorny bamboo is unique in comparison with other bamboo species. Four species of bamboo reported that thorny bamboo showed higher physical pulp properties compared to those of temen
bamboo (*Gigantochloa atter*), tali (*Gigantochloa apus*) and gombong (*Gigantochloa atter*). However, this thorny bamboo has not yet fully utilized in Indonesia [2].

Thorny bamboo, in fact, shows characteristics as potential material for dissolving pulp. Dissolving pulp is a particular pulp that has a high content of cellulose (>90%) [3]. The production process of dissolving pulp is arranged so as to yield pure cellulose content by obliterating lignin and hemicellulose from the system [4]. The rayon pulp requires the minimum content of alpha-cellulose of 95% [5]. The purification of alpha-cellulose can be obtained by pre-hydrolysis, kraft pulping and pulp bleaching.

Study on dissolving pulp from bamboo had been reported [6]. However, in this recent study, two different growing sites of the thorny bamboo are discussed that is distinguished this recent study to the previous one. Thorny bamboo used in this recent study was from Sumatra while in the previous study was from West Java. Moreover, this recent study used a different method of pre-hydrolysis. This study aimed to determine characteristics of thorny bamboo from highland (TB1) and lowland (TB2), as well as the process of dissolving pulp.

**2. Materials and Methods**

2.1. Materials

Thorny bamboo was collected from two different growing sites. As the representative of highland, bamboo was collected from Agam Regency (West Sumatra Province) in 2015 coded as TB1. Bamboo from Siak Regency (Riau Province) was collected as lowland bamboo in 2017 coded as TB2. The chemicals used in the study were acetic acid 5%, sodium hydroxide, sodium disulfide, chlorine dioxide, peroxide, and aquades.

2.2. Methods

Bamboo culms were harvested from near-center of the clump, which considered as adequately matured. The culms then sorted by removing the nodes, outer-skin, and inner-skin. Chips (± 2.5 x 2.5 x 0.5 cm) were subsequently made from the sorted culms. The culms yielded 66.01% of bamboo chips. The chips were air-dried and the moisture content was recorded. Fiber dimension and chemical content of the chips were analyzed.

2.2.1. Process of dissolving pulp

*Chips pre-hydrolysis*

The chips were pre-hydrolyzed with 5% acetic acid in condition: chips to solution ratio 1:5, cooked in the digester at a maximum temperature of 165 ºC for 60 minutes at the maximum temperature.

*Kraft pulping*

The condition of Kraft process is presented in Table 1. Pulp yield and kappa number were determined after the pulping process. The resulted brown pulp was subsequently bleached to improve alpha-cellulose content and to remove impurities.

| Active alkali (%) | 25 |
| Sulfidity (%) | 32 |
| Chip to solution Ratio | 1:4 |
| Maximum Temperature (ºC) | 165 |
| Cooking time at max temperature (mins) | 60 |

Table 1. The Kraft pulping condition for thorny bamboo.
Pulp bleaching
Pulp bleaching was followed by Elemental Chlorine Free (ECF) process with stages of Do, Ep,D1,D2 (chlorine dioxide, extraction-peroxide, chlorine dioxide 1, chlorine dioxide 2). The bleaching condition is presented in Table 2. The bleached pulp was then analyzed for rayon pulp based on SNI Pulp Rayon 0938:2010.

Table 2. The condition of bleaching for thorny bamboo dissolving pulp

| Parameter          | Do     | Ep | D1  | D2  |
|--------------------|--------|----|-----|-----|
| CIO2, %            | 0.22 KN|    | 1   | 0.5 |
| NaOH, %            |        | 1  |     |     |
| H2O2, %            |        | 2  |     |     |
| Consistence, %     | 10     | 10 | 10  | 10  |
| Temperature, °C    | 60     | 70 | 75  | 75  |
| Reaction time, mins| 60     | 60 | 180 | 180 |
| Final pH           | TB1    |   | 2.19|     |
|                    | TB2    |   | 2.22|     |

Remarks: KN = Kappa Number

3. Results and discussion

3.1 Morphology and habitat of thorny bamboo
Thorny bamboo has shoots that sheathed with black cilia, sometimes with a yellow line on the sheaths. Young culms are covered by whitish wax thus the color looks greyish. The culms are full of dense thorns. Branches are starting from above the ground with the main branch is bigger than lateral ones. The culm sheath is deciduous with earlike auricle up to 5 mm long, stand or spread [1].

For the sample, the considerable sized of culms at the near-center of the clump were chosen as they are considered as mature culm. Sample TB1 was collected from farm at the hilly area of 900-910 m asl, while sample TB2 was collected from a palm oil field at 0-5 m asl. The clump of TB1 was comparably bigger than that of TB2, as diameter of clump of TB1 was about 10 m and TB2 was around 7 m, which also indicated that the clump of TB1 was older than TB2 even though the exact age of the clumps were difficult to be specified since the bamboo grew naturally (wild). The culms of TB1 were thicker than that of TB2, as was indicated by the chips thicknesses that were 2.5 mm and 1.5 mm, respectively.

3.2 The material characteristics of thorny bamboo
Material characteristics were fiber dimension and chemical content that were analyzed to determine the quality of the material and is presented in Table 3. Fiber dimension included fiber length, fiber diameter, lumen diameter, and cell wall thickness. Fiber dimension is significantly affected by the growing site [7], presumably due to the soil chemicals and nutrients of the growing site.

The fiber of TB2 was longer but presumably had a thinner cell wall than those of TB1 since the alpha-cellulose content in TB1 was higher in TB1. The cell wall consists of primary and secondary layers. The primary layer contains pectin [8]. Meanwhile, the second layer consists of layers of S1, S2, and S3 in which S2 is usually in bigger portion than S1 and S3. In S2, the percentage of cellulose is bigger than lignin and hemicellulose [8]. The higher alpha-cellulose content of TB1 assumed the thicker cell wall in TB1 compare to that in TB2.

Alpha-cellulose in TB1 and TB2 were 51.28% and 36.90%, respectively. TB1 showed higher alpha cellulose content than the study of Kardiansyah [9] but lower than in the study of Purwita & Sugesty [6]. The difference is assumed due to the different growing sites. Samples of the previous studies were
obtained from Arcamanik forest in West Java that was cultivated and well maintained (4 years old). In contrast, in these recent studies, the samples were harvested from wild clumps with undetermined age.

Table 3. The material quality of thorny bamboo

| No. | Characteristics                        | The growing site/origin | a [9] | b [6] |
|-----|----------------------------------------|-------------------------|-------|-------|
| 1   | Fiber dimension                        |                         |       |       |
|     | Fiber length, mm                       | 2.62 ± 0.18             | 3.22 ± 0.51 | 2.22 | 3.31 |
|     | Fiber diameter, µm                     | 18.48 ± 4.14            | 14.85 ± 3.59 | 15.38 | 20.04 |
|     | Lumen diameter, µm                     | 6.20 ± 2.47             | 4.74 ± 1.65 | 5.43 | 8.53 |
|     | Cell wall thickness, µm                 | 6.14 ± 1.16             | 5.05 ± 1.48 | 4.98 | 5.76 |
| 2   | Chemical content, %                    |                         |       |       |
|     | Extractives                            | 4.32                    | 2.23 ± 0.03 | 3.68 | 3.1  |
|     | Lignin                                 | 17.57 ± 0.75            | 20.08 ± 1.42 | 27.51 | 24.32 |
|     | Hemicellulose                          | 28.31 ± 0.16            | 27.40 ± 2.17 | 25.49 | 25.23 |
|     | alpha-cellulose                        | 51.28 ± 0.49            | 36.90 ± 1.01 | 46.6  | 58.24 |

3.3 Dissolving pulp

In order to obtain a qualified dissolving pulp, the hemicellulose, lignin, and other impurities were eliminated as many as possible while still retain the higher yield as possible. Therefore, it is required to determine the most suitable cooking condition for a specific material, in this case for the thorny bamboo. Pre-hydrolysis before Kraft pulping was aimed to obtain dissolving pulp with high alpha-cellulose and the lowest hemicellulose content [11].

Pre-hydrolysis assists the removal of hemicellulose in two stages which is before and after the Kraft process [12]. Pre-hydrolysis on TB1 with 5% acetic acid reduced hemicellulose content from 36.48% to 31.32% (Table 4). Pre-hydrolysis may reduce hemicellulose content as many as 14.14%. Pre-hydrolysis with water after some particular time would break the xylene chains and acetyl groups as a result of hydrolysis reaction by hydronium ion. At the further stage of the pre-hydrolysis, acetic acid that is resulted from the break of the acetyl group would provide the addition of hydronium ion that would improve the kinetic of the pre-hydrolysis [11].

Table 4. Pre-hydrolysis Kraft of thorny bamboo

| No. | Sample | Hemicellulose content at acetic acid Pre-hydrolysis (%) | Kraft process |
|-----|--------|--------------------------------------------------------|---------------|
|     |        | 0% | 5% | Pulp yield (%) | Kappa number |
| 1   | TB1    | 36.48 | 31.32 | 35.25 ± 2.87 | 9.22 ± 0.83 |
| 2   | TB2    | Unavailable data | Unavailable data | 36.28 ± 0.01 | 16.04 ± 1.25 |

TB1 and TB2 showed a comparable yield of kraft pulp, 35.25 and 36.28% respectively. However, the kappa number was 9.22 for TB2 and 16.04 for TB1, which meant the remaining lignin content in TB2 pulp was higher than that in TB1 pulp. This result was in agreement with lignin content in the bamboo material in which higher in TB2 (Table 3). Bleaching was then conducted to reduce the lignin content of the pulp. The bleached pulp was then analyzed to the quality of rayon pulp (Table 5).

TB2 showed alpha-cellulose content that met the requirement of rayon pulp while TB1 was only slightly under the standard (Table 5). Bleaching increased alpha-cellulose content in the bleached pulp compare to that in Kraft pulp. Yet, other parameters did not meet the standard of rayon pulp. The low brightness indicated that pulp still contained lignin, therefore, viscosity test was unnecessary. Further research to reduce ash content must be considered, e.g. to add mechanical process in such was conducted by Purwita and Sugesty [6] or chemically by adding the additive to dissolve ash materials.
4. Conclusion

In conclusion, concerning the material characteristics, the thorny bamboo from both locations can be considered as the material of dissolving pulp. The fiber length was 2.62-3.22 mm and alpha-cellulose content was 36.90-51.28%. The mechanical process needs to be considered in the pre-treatment to reduce ash and mineral content.

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Table 5. Dissolving pulp of thorny bamboo

| No. | Parameter                        | Sample    | SNI pulp rayon |
|-----|----------------------------------|-----------|----------------|
| 1   | Alpha cellulose (%)              | 93.58     | min. 94        |
| 2   | Solubility of NaOH 18%, (%)      | 2.23      | max. 4.9       |
| 3   | Solubility of NaOH 10%, (%)      | 4.66      | max. 7.9       |
| 4   | Extractives (dichloromethane), (%)| 0.37      | max. 0.2       |
| 5   | Ash content (%)                  | 5.93      | max. 0.15      |
| 6   | Acid insoluble ash content (mg/kg)| 9552    | max. 80        |
| 7   | Calcium content (mg/kg)          | 1981.1    | max. 150       |
| 8   | Iron content (mg/kg)             | 232.18    | max. 8         |
| 9   | Brightness (% ISO)               | 24.64     | min. 88        |
| 10  | Moisture content (%)             | 3.39      | max. 11        |