Delignification of Abaca Fiber (*Musa textilis*) as Potential Substitute for *Eucalyptus pellita*

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Abstract. Five years old *Eucalyptus pellita* is a raw material used to manufacture pulp in Indonesia. In the field, the cropping cycle of this wood is still considered too long, so the need to develop other alternative raw materials that have characteristics similar to the fiber planting a shorter cycle. One of the alternative raw materials is abaca fiber (*Musa textilis*). Abaca fiber is preferred over other fibers because of its good tensile strength and resistance to rotting. In the present work, delignification of abaca fiber was carried out by kraft pulping process and characterized in term of their mechanical properties. Abaca fibers were treated with kraft pulping and oxygen delignification. Eucalyptus kraft pulp was also characterized as a comparison. Kappa number and viscosity decreased when the active alkali charge increased. Kraft pulp abaca with high cooking results and good viscosity is easily delignified by converting oxygen to low kappa numbers (7-9) without significant loss in viscosity. In addition, from the final results, the kappa number and viscosity, it was shown that abaca pulp has very high strength. Although oxygen delignification for lower kappa quantities can be considered, in terms of the properties of the pulp the abaca fiber is suitable as a raw material for pulp.

Keywords: abaca fiber, kraft pulping, oxygen delignification

1. Introduction

As the pulp and paper industry grows more rapidly, the demand for pulp raw materials also increases. Pulp raw materials are generally derived from broad wood plants and needle leaf wood plants. At present, 5-year-old *Eucalyptus pellita* and *Acacia mangium* are the raw materials used for pulp production in Indonesia. The problem in the field is that the wood planting cycle is still considered too long so that it needs to develop other alternative raw materials that have fiber characteristics similar to shorter planting cycles [1]. One alternative raw material that can be used is abaca banana fiber (*Musa textilis*). Abaca fiber (*Musa textilis*) is a non-wood fiber (non-wood fiber) that can be used as an alternative material in making pulp because it contains about 68.32% cellulose, 19% hemicellulose, and 12-13% lignin [2]. Abaka is a superior fiber with high tensile and folding strength, high porosity, resistance to saltwater damage, and a long fiber length of up to 3m.

Abaca (*Musa textilis* Nee) is a type of banana plant which produces fiber, including in the family Musaceae. Abaca is known by several names such as banana fiber, Manila Hemp, Manila Henep, kofo tree or hote. In some areas in Indonesia, abaca plants are known by various names such as Banana
Manila (Manado), Cau Manila (Sunda), Kofo sangi (Minahasa). The main production of this abaca plant is abaca fiber which was originally only used as a raw material for making ship ropes and clothing materials [3]. However, further research along with the development of technology and human civilization has been able to maximize the use of abaca fibers. Abaca fibers are known as high-quality fibers that are used as raw materials for various industries such as textiles, paper and even automotive [4]. Abaca fiber has been used to make submarine cable wrappers, rigging on ships, paper money, checks, filter paper and wrapping paper (Bank Indonesia). In the automotive field, Mercedes Benz has used a mixture of thermoplastic polypropylene and abaca threads on car body parts [2].

For abaca, in some studies still using the soda pulping process [1][2]. This method is very wasteful with chemicals, especially soda. Kraft process is known to produce pulp with a higher strength compared to the soda process, in this process all types of wood can be used and the benefits gained from this process are the process of recovering relatively high chemicals and producing energy that can be reused. Kraft process is a type of pulp manufacturing process that is commonly used by the pulp industry in Indonesia with raw materials, especially the type of broadleaf wood (hardwood). The most important factor in the kraft process is the concentration of the cooking solution. The increase in concentration causes an increase in the rate of delignification and results in an increased effect of cellulose solution. Active alkali (AA) concentration on the weight of wood that is often used is 15-20%. An increase in active alkali concentration that is too high causes greater cellulose damage than lignin, thereby reducing the yield and strength of the pulp.

Depending on the order of subsequent bleaching and the target paper level, kraft pulp that is not bleached with kappa number 18-30 is usually made from eucalyptus [3–5]. However, the element chlorine is still commonly used in pulp bleaching. Several studies have also reported oxygen delignification of the eucalyptus kraft pulp. However, there are no studies that explicitly aim at achieving very low kappa numbers for abaca pulp. An effective reduction in the content of lignin residues in kraft pulp without a negative effect on the strength properties of the pulp will be very important. on the one hand, for environmental protection and, on the other hand, to reduce bleaching costs.

The aim of this study is to investigate the possibility of producing abaca pulp with a low residual lignin content for bleaching using conventional kraft pulp followed by oxygen delignification. This research is part of a larger research project that aims, in addition to cooking experiments with non-wood raw materials, on the detailed characterization of liquids released related to cooking, oxygen delignification. so that it has the potential to reduce the use of wood as pulp raw material.

2. Materials and Methods

2.1 Materials

The materials used are abaca fiber (Musa textilis) from Aceh and Eucalyptus pellita wood from Jambi Province (Table 1). The chips and fiber are filtered (SCAN-CM 40:94), dried and stored at 25% water content. The concentration standard of NaOH and Na2S for pulping was set to 97.0 g / l and 32.4 g / l respectively.

| Wood and Fiber Characteristics | Abaca Fiber | Chip Eucalyptus Pellita |
|-------------------------------|-------------|------------------------|
| Density (g/cm³)               | 1.5         | 0.469                  |
| Cellulose                     | 68.32%      | 68.85%                 |
| Hemi cellulose                | 19%         | 18%                    |
| Lignin                        | 12-13%      | 28.09%                 |
| Moisture content              | 10-11%      | 31.6%                  |
| Ash content                   | 4.8%        | 0.4%                   |
2.2 Kraft pulping
Cooking liquor including sodium hydroxide and sodium sulfide were prepared from Merck products. Concentrations of cooking liquor were analyzed according to SCAN–N 2:88 standard. Then, on the basis of concentration of cooking liquor and the ratio of liquor to chips weight (L/W). The cooking was carried out in a rotating digester Haato 6 chambers with active alkali charge of pulping liquors. The cooking conditions are shown in Table 2. Each chamber of digester was filled with 300 gram of oven-dried chips and the wood ratio between chips and liquid was 1: 3.5. The chips, white liquor, and solvent were added into chambers and placed in digester. Impregnation time consisted of 3 stages, the first stage was from 27 to 100°C for 30 minutes, the second stage was from 100 to 132°C for 30 minutes and the third stage was from 132 to 165°C for 30 minutes. The cooking process was at a maximum temperature of 165°C for 90 minutes. The resulted pulp was sieved through a screen somerville. Pulping yield was obtained gravimetrically by weighing the oven-dry pulp and reported as percentage of the original wood. Viscosity and kappa number were determined by TAPPI T 236 cm-85 and TAPPI T-230 om-89 respectively.

| Table 2. Cooking Conditions |
|-----------------------------|
| Parameters                  | Conditions               |
| Active Alkali (%)           | 16, 17, 18, 19, and 20 |
| Sulfidity (%)               | 25 - 28                  |
| Maximum temperature (°C)   | 165                      |
| H-Factor                    | 800                      |
| Wood chips dry mass (g)     | 300                      |
| Liquid ratio                | 3.5                      |

2.3 Oxygen delignification
Oxygen delignification is carried out in a rotating reactor with an electric heater and a volume of 20 liters, consisting of 6 individual tubes of 100 mL each. Pulp samples with 4 grams each were placed into the reactor in a medium consistency in Table 3 and heated to a predetermined temperature. The pulp is washed with distilled water. Pulp that has been washed, then filtered, and dried then tested its quality. The experimental design used is completely random in factorial settings.

| Table 3. Oxygen Delignification Conditions |
|--------------------------------------------|
| Parameters                                  | Conditions               |
| Pulp consistency (%)                        | 10                       |
| Reaction time (min)                         | 60                       |
| Maximum temperature (°C)                   | 85-90                    |
| Alkaline charge (% NaOH)                   | 2                        |
| Wood chips dry mass (g)                     | 4                        |
| Oxygen preasure (bar)                       | 20                       |

2.4 Delignified Pulps Analysis
Kappa number of pulp and pulp viscosity were determined in accordance with the procedures of TAPPI T 236 cm-85 and TAPPI T-230 om-89 respectively. Lignin content, Delignification degree (DD), and Degree of Polymerization (DP) of pulping was calculated following the formula as follows:
Lignin Content (Klason) = 0.152 × Kappa Number

\[ DD\% = \frac{\text{total lignin of wood} - \text{residual lignin of pulp}}{\text{total lignin of wood}} \times 100\% \]

\[ DP^{0.905} = 0.75 [\eta] \]

\[ [\eta] = \text{intrinsic viscosity} \]

3. Result and Discussion

3.1 Kraft pulping

The kraft process is carried out to determine the pulp properties of abaca. The kraft method is 25% sulfidity, 16-20% active alkali (AA) at a cooking temperature of 165°C and a cooking time of 90 minutes at maximum temperature, as is commonly done in the pulp and paper industry. The main purpose of this cooking process is to reduce the lignin content measured from the kappa number (KaNo) according to the minimum standard as a reject pulp. The nature of the pulp produced from the process is presented in Table 4. The increase in active alkali load causes the total pulp yield to decrease as shown in Table 4. The higher the active alkali load used during the cooking process, the lower the pulp yield. This is caused by increasing levels of delignification. The amount of delegated lignin results in better physical quality of the pulp. However, cooking with an excessive active alkali load can also cause extensive fiber degradation [10]. The use of an active alkali load that is too low will also produce more unexpected rejection in the pulp. Reject is caused by wood chips and raw fiber in the cooking process because once the delignification process is not completed, the pulp quality decreases. Therefore, the use of an active alkali load needs to be considered to get the best pulp quality.

| Material         | Active Alkali (%) | Total Yield (%) | Screen Yield (%) | Kappa Number | Viscosity (ml/g) | Lignin Klasson (%) |
|------------------|-------------------|-----------------|------------------|--------------|-----------------|--------------------|
| Eucalyptus pellita | 16                | 53.14           | 52.84            | 16.69        | 954             | 2.53688            |
| 17               | 53.2              | 53              | 15.87            | 918          | 2.41224         |
| 18               | 51.92             | 51.82           | 14.99            | 892          | 2.27848         |
| 19               | 50.77             | 50.7            | 14.6             | 847          | 2.2192          |
| 20               | 50.6              | 50.6            | 13.4             | 810          | 2.0368          |
| Musa textilis    | 16                | 58.6            | 58.4             | 13.24        | 955             | 2.01248            |
| 17               | 55.44             | 55              | 12.45            | 939          | 1.8924          |
| 18               | 52.54             | 52.32           | 12.2             | 917          | 1.8544          |
| 19               | 50.35             | 50.22           | 10.85            | 880          | 1.6492          |
| 20               | 48.2              | 48              | 10.15            | 848          | 1.5428          |

The increase in active alkali load affects the decrease in pulp yield. It can be concluded that every 1% increase in active alkali content will reduce 0.15% pulp yield. The high decrease in hardwood yield due to high hemicellulose content [6]. For Eucalyptus pellita, the maximum pulp yield is 17% active alkali. Carbohydrates, cellulose, and hemicellulose are very unstable in alkaline solutions. During the process of cooking with alkalis, damage to glycosidic bonds occurs. This results in the separation of the main chain chains and carbohydrate chains. Termination produces low molecular weight soluble compounds which cause reduced yield. Termination of carbohydrate chemicals during the process of making alkalis involves several types of reactions that are influenced by concentration but do not depend on the presence and ions used in the kraft process.

The high kappa number shows the high lignin content in the pulp produced after the cooking process. Pieces of raw wood and fiber contain cellulose, hemicellulose and other impurities. Active alkali charge
was observed to get the target kappa number. Within the normal range, the kappa number is expected to be <20 according to the alkaline preparation standard where the range of the kappa standard for *Eucalyptus pellita* is 12-18 [8]. A decrease in kappa number is caused by the use of an excessive active alkaline load which damages cellulose fibers and not only lignin is dissolved but also cellulose is dissolved in liquid. Figure 1 shows that the kappa number decreases with an increasing active alkali load. This is due to the increased degradation of lignin with a higher active alkali load in the liquor used. At the active alkaline load level of 16-20% for *Musa textilis* and *Eucalyptus Pellita*, the standard kappa number ≤18 is reached. However, *Musa textilis* produced a lower kappa number compared to *Eucalyptus pellita*.

The delignification degree and the amount of kappa pulp are significantly affected by active alkali. Figure 1 shows the effect of the amount of active alkali on the level of delignification and the amount of kappa from the pulp produced. The delignification degree increases with the increasing amount of active alkali. As a result, the amount of kappa pulp decreases with increasing amount of active alkali. At an active alkaline amount of 20%, the delignification rate reaches around 92% for *Eucalyptus pellita* and 88% for abaca. The concentration of OH\(^-\) and HS\(^-\) in liquor significantly influences the level of delignification. It is well understood that HS\(^-\) increases the cell wall swelling and facilitates delignification. The relatively low kappa rate of 13-16 (at 20% active alkali) is achieved with an H-factor of 800. It seems that Abaca is better prepared than *Eucalyptus pellita* wood because abaca kraft pulp requires an H-800 factor to reach a kappa pulp number of 10,15.

![Figure 1](image-url). Effect of active alkali amount on delignification degree

The higher the viscosity, the higher the carbohydrate resistance. The nature of good physical endurance depends on the bond between fibers [10]. Table. 4 shows that viscosity is low with increasing active alkali load. High viscosity levels on active alkali loads are low because of the density or bonding between strong fibers, even though cellulose is also degraded by liquids. A high active alkali load will produce low viscosity due to high polymerization rates. Bonding between fibers, especially cellulose, is degraded by liquor, resulting in low fiber strength and high pulp solubility [4]. The high viscosity of pulp is expected to improve pulp quality, especially pulp and tensile strength. Viscosity and kappa numbers are used to determine the content and loss of degradation of lignin and carbohydrates in the pulping process. Lignin is widely lost and cellulose degradation increases with increasing active alkali content used in the pulping process. Lignin is lost by breaking the bond between the α- and β-aryl ether bonds in the propane unit. Subsequent termination by the liquid at the hydrolysis temperature decreases the amount of cellulose.
Figure 2. Effect of Active alkali on Degree of polymerization

As with cellulose, the decrease in hemicellulose causes a decrease in the viscosity of the pulp caused by a reduced degree of polymerization [11]. Loss of hemicellulose at a low degree of delignification can produce a higher viscosity than the pulp. A decrease in viscosity of a paper pulp that cannot be removed by more than 20% can increase the content of OH⁻ which decreases cellulose lignin. The degradation of cellulose by alkali can be continued by peeling off the reaction and hydrolysis of the alkali [12].

3.2 Oxygen delignification
The kappa number, yield, and viscosity of the kraft pulps are presented in Table 5 before and after oxygen delignification. It can be seen that the degree of delignification at the same sodium hydroxide load depends on the initial kappa number [11]. For pulp with an initial kappa number 10-16, the delignification rate is between 30 and 38% and a final kappa number between 7 for pulp kraft abaca and 12 for pulp kraft eucalyptus is obtained. These results indicate that kraft pulp with low kappa number can also be easily removed by oxygen delignification [12][5].

The lower the kappa number after cooking, the lower the kappa number after oxygen reduction. The results showed that the lignin content in the oxygen-delignification stage pulp one level could be reduced to a low level either by reducing lignin residues during cooking or by increasing the alkali content at the oxygen delignification stage. However, pulp with lower lignin content (kappa number 7-9) and great viscosity can only be obtained if the amount of lignin residue is quite low after cooking.

Great viscosity of pulp after oxygen removal has a degree of polymerization for pulp of ≥ 1200 [13] (according to ISO 5351: 2012 standards) except for pulps cooked with AA 19-20% shown in figure 3. At the final kappa number 9.2-10, 62 in Eucalyptus pellita, the highest viscosity in the pulp case of AA 16% is 861.98 ml/g together with a low alkaline load (2%) in the oxygen delignification stage. At the final kappa number of 7.04-8.4, the highest viscosity for abaca kraft pulp at AA 16% is 886.02 ml/g higher than that of the Eucalyptus pellita kraft pulp. In the last kappa number around 7, the viscosity is quite low. It can be seen from this result that delignification kraft pulp to kappa numbers as low as 7 by one-stage oxygen delignification
Table 5. Properties of the kraft pulps before and after oxygen delignification

| Material         | Active Alkali (%) | Initial Kappa Number | Kappa Number Final | Initial Viscosity (ml/g) | Viscosity Final (ml/g) | Yield (%) |
|------------------|-------------------|----------------------|--------------------|-------------------------|------------------------|-----------|
| *Eucalyptus pellita* | 16                | 16.69                | 10.62              | 954                     | 861.98                 | 96.46     |
|                  | 17                | 15.87                | 10.36              | 918                     | 838.45                 | 95.67     |
|                  | 18                | 14.99                | 9.68               | 892                     | 820.32                 | 95.73     |
|                  | 19                | 14.6                 | 9.37               | 847                     | 778.42                 | 95.77     |
|                  | 20                | 13.4                 | 9.2                | 810                     | 748.55                 | 94.72     |
| *Musa textilis*  | 16                | 13.24                | 8.4                | 955.82                  | 886.02                 | 95.01     |
|                  | 17                | 12.45                | 7.62               | 939.68                  | 870.50                 | 95.73     |
|                  | 18                | 12.2                 | 7.48               | 917.50                  | 833.43                 | 95.56     |
|                  | 19                | 10.85                | 7.20               | 880.17                  | 795.94                 | 94.80     |
|                  | 20                | 10.15                | 7.04               | 848.98                  | 768.83                 | 95.66     |

Figure 3. Effect of Oxygen delignification on Degree of polymerization

results in a severe reduction in pulp strength, as demonstrated by the low viscosity observed [3]. It has thus been proven to be possible to abolish selected pulp kraft abaca by oxygen delignification to pulp with very low kappa numbers (7-9) and great viscosity (degree of polymerization ≥ 1200). Based on the data, abaca fiber is more effective for delignification of lignin polymers than *Eucalyptus pellita*. This result is very interesting for modern pulp mills, which aim, for example, to use ECF or TCF bleaching techniques. However, more work needs to be done to clarify the bleaching capability, and especially the feasibility of the pulp strength, of this pulp with low residual lignin content.

4. Conclusions

In this study, abaca as delignified by kraft pulping and oxygen-alkali delignification subsequently becomes a pulp with a low kappa amount. The most important findings from various different alignment experiments are a higher alkaline load can increase alkaline residues and reduce yield, kappa number and viscosity and the active alkali (AA) has a significant effect on the kappa number and viscosity of kraft pulp obtained. Lower AA (6-18%) results in higher viscosity and pulp yields compared to higher
AA (19-20%) at the level of delignification. Kraft pulp with high cooking results and good viscosity is easily delignified by converting oxygen to low kappa numbers (7-9) without significant loss in viscosity. A higher level of viscosity obtained from low AA compared to high AA was also observed in oxygen-depleted pulp. In addition, from the final results, the kappa number and viscosity, it was shown that abaca pulp has very high strength. Although modified pulp and oxygen delignification for lower kappa quantities can be considered, in terms of the properties of the pulp the abaca fiber is suitable as a raw material for pulp and has the potential to substitute Eucalyptus pellita.

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