Potentiality of Banana (Musa) Stem as Raw Material in Chemical Nonwood Pulping

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ABSTRACT

Wood is not sufficient in many countries to meet the rise demand for paper and pulp. In recent years, a lot of researches have been done to find a new, non-wood raw material for paper production especially using agricultural waste. Agriculture industry is one of the main industries in Malaysia which has generated a large amount of waste every year such as banana stem, rice hull, sugarcane bagasse and wheat straw. These are regarded as abundant, inexpensive and readily available natural resources for pulping industry. The purpose of this paper is to study of the pulping potentialities of banana stems which are growing in Malaysia. In this research the banana stem is used as raw material in the pulping process for the purpose of producing cellulose as pulp. The chemical pulping method which is used in the study is soda pulping, where NaOH is the main chemical substance used in cooking and with anthroquinone as the additive. Temperature, residence time and dosage of chemical were the parameters to be manipulated in this non-wood chemical pulping process to get an optimum condition for pulping. A 3 litre batch reactor was used in this non-wood chemical pulping process. The concentration of NaOH used was varied from 10 – 45 % and cooking temperature was varied from 100 – 200 °C. The ratio of solid to liquid is set at 1:8 and also the cooking period was varied from 30 – 210 minutes. The result shows that the optimum

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yield of pulp from this study is at 20 % w/w NaOH, cooking at 160 °C with 120 minutes. The yield of pulp is around 30 %. The cellulose content in the pulp produced is as high as 90 %.

***Keywords**: Pulp, non-wood, pulping, banana stems, NaOH*

Introduction

Egyptian started to use non-wood plant species as paper at 3000 BC. They pressed pith tissue of papyrus sedge (Cyperus papyrus L.) to make surface writing. A Chinese, Ts'sai Lun invented paper in AD 105. He made writing sheet using fibres from hemp rags and mul-berry (Morus ala L.). Straw was used for the first time as a raw material for paper in year 1800.

According to Kyrklund [1], nonwood fibrous raw materials are predominant in Asia like China, India, Iran, Pakistan and Bangladesh. Commercial non-wood pulp production has been estimated to be 6.5 % of the global pulp production and is expected to increase [2]. In the United State paper contains only about 2 % of nonwood fibers on average [3]. Several reasons have been given to explain this, which are the lack of forest resources in some countries, size of non-wood pulp and paper mills are smaller than wood-based mills and less stringent pollution requirements from governments to promote investment in domestic paper manufacture. The advantages of using non-wood fibres as raw material in pulping process are, it is replaceable, low lignin content [4, 5] and lesser chemical usage and effluent.

Due to the rise in the rate of deforestation, it may cause the shortage of raw material which rely on hard wood and soft wood as raw material and at the same time the demand for paper is getting increased. Alternate raw materials such as non-wood sources from agricultural wastes have received a substantial attention [5-8].

Agricultural wastes like wheat straw, rice straw, molasses and bamboos are being used as raw material in pulping process to recover the cellulose [9]. Most of the non-wood fibres are derived from annual plants. They grow on farmland and could be harvested each year with high yields and they can be replaced annually as a renewable resource if compared to the wood, which need longer growth cycles. The recent interest in the utilisation of agricultural fibres has promoted research into their potential as raw material for the pulp and paper industry [4].

The production of banana (Musa acuminata Colla) in Malaysia has generated a large amount of residues because each plant will only produce the banana fruits once. After harvesting the fruits, the stems are cut and usually left in the soil plantation to be used as organic materials. Banana stems can be easily treat from the lignin and require milder and faster cooking conditions comparing to wood fibre sources [5].

Banana is a general term acceptance a number of species in the genus Musa of the family Musaceae. It is grown in the warm, humid tropics like Malaysia. In Malaysia, banana bushes are easily to be found whether in fruit farms or backyard of houses. Banana bushes take about 15 months to be matured. The banana plant is a large herb with succulent, very juicy stem, and could reach a height of about 2.75 m.

According to Biermann [6], the factors influence the suitability of raw materials for use in paper are the ease of pulping and yield of usable pulp, the availability and dependability of supply, the cost of collection and transportation of fiber source, the fiber morphology, composition, and strength including the fiber length, diameter, wall thickness, and fibril angle, the presence of contaminants and the seasonability of the supply. In this study, we only focus on the ease of pulping and yield of usable pulp.

There are four categories of pulping processes which are chemical pulping, semi-chemical pulping, chemi-mechanical pulping and mechanical pulping. Chemical pulping rely on the effect of chemicals to separate fibers. The more the chemical used the lower the yield and lignin content since chemical action degrades and solublizes components of wood. On the other hand, chemical pulping yields individual fibers that are not cut and give strong papers since the lignin, which interferes with hydrogen bonding of fibers, is largely removed.

Soda pulping was invented in England by Burgess and Watts in 1851 [3]. The Soda process is based on NaOH and has been widely used in the processing of nonwood fibres [10]. Chemical recovery for soda process is simple compared to the others chemical pulping processes. Chemical separations may cause damage to the fibre length. To overcome these problem, additives such as anthroquinone is used to improve the dissolution of lignin while keeping carbohydrate losses low. Many researchers [11-13] have done several researches on chemical pulping using nonwood fibrous raw material. The main objective of this research is to set up an experiment for non-wood chemical pulping process to study the potential of banana stems as raw material in pulp and paper industry to replace the wood.

Approach and Methods

a. Raw Material Preparation

Raw material which is used for this research is banana stems, which were collected from the fruit farm. The banana stems were cut into ½ in width and 1 in length. The banana stems did not undergo drying process. The oven dry method was used to determine the moisture content in the banana stem. 50 g of banana stem was taken and dried in the oven at 105°C until the mass of the dried banana stem did not change. After that culculate the moisture content of the banana stem using the formula below:

$$\text{Moisture content, } \omega = \frac{m_1 - m_2}{m_1} \times 100$$

where: m_2 mass of banana stem after oven dried
m_1 mass of banana stem before oven dried (50 g)

80 g (o.d) of banana stem will be fed into the batch reactor. The gross mass of banana stem was calculated based on the moisture content.

$$\text{Gross mass of banana stem, } m = \frac{100}{100 - \omega} \times 80$$

b. NaOH Stock Solution Preparation

Stock solution of NaOH was prepared by dissolved 500 g of NaOH solid into the 2 liters deionize water. The stock solution was diluted by transfered 25 ml of stock solution into the 250 ml volumetric flask and filled up with the deionize water which represented 10 times dilution. Transfered 20 ml diluted NaOH solution from the 250 ml volumetric flask into the conical flask and added 3 to 4 drops of fenoftalein. Violet colour appeared inside the flask.

The diluted NaOH was titrated with the 50 ml HCL 1 N until violet color disappear and titrations reading were recorded. Normality of NaOH will be calculated based on formula:

$$N_1V_1 = N_2V_2$$

The concentration of NaOH(x) stock solution was calculated based on formula:

x = molecular weight × Normally × dilution factor
Molecular weight is based on NaOH - 31

c. Determine the Volume of Liquor Needed in Pulping

Take an example whe we need to prepare 20 % NaOH with banana stem 80 g with liquor to wood ratio is 8:1. The first step is to calculate the mass of liquor needed. Since we are going to cook 80 g of the banana stems, the mass of liquor need is 640 g. Liquor for alkaline pulping is based on Na_2O. Thus, the mass of chemical charge is 25 % of 80 g banana stem is 20 g. The conversion factor to convert Na2O to NaOH is 1.291, then the mass of NaOH needed is 25.82 g. Since we need to have 640 g of liquor, the mass of water added is 614.18 g. Assumption was made that all the liquor specific gravity is 1, the density of all liquor is 1000 g/L. The total volume of liquor is 640 mL.

If the concentration of NaOH stock solution is 160 g/L which was obtained in part

The concentration of the NaOH needed is 40.34 g/L. The volume of NaOH stock solution can be obtained by using the concentration of NaOH needed, which is 159.4 mL. The volume of water need to be added to make the liquor up to 640 mL is 480.6 mL.

d. Pulping Process

Banana stems with needed gross mass were cooked with NaOH concentrations of 10, 15, 20, 25, 30, 35, 40 and 45 %. The banana stem chips were cooked in a fabricated 3 litre digester with temperature 160 °C and cooking time 90 minute. After the digestion was completed, the cooked pulp and spent liquor are discharged. The incomplete cooked particles were then removed on perforated screens and taken as the reject. The spent liquor is separated from the pulp by counter current washing. The pulp is then diluted to low consistency and small-sized contaminants are removed by fine screens. The cleaned stock is then thickened and stored for subsequent analyses. Yield of the pulp produced is calculated.

The same procedure was repeated with difference cooking times. The banana stem chips were cooked in the digester with cooking times of 30, 60, 90,120, 150, 180 and 210 minute. The temperature was set at 160 °C and the concentration of NaOH was 20 %. After cooking, the same procedure was done to get the mass of the pulp produced to calculate the yield.

The third set of experiments was repeated with different cooking temperatures. The dried banana stem chips were cooked in the digester with cooking temperatures were 100, 120, 140, 160, 180 and 200 °C. The concentration of NaOH used was 20 % and the cooking time was 150 minute. The mass of the dried pulp produced was recorded after the cooking.

Results and Discussions

The first set of experiment is to analyse the effect of the chemical charge which is NaOH was used in this study on the yield of pulp. The result is shown in Figure 1.

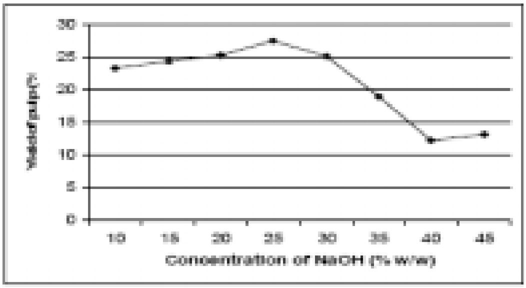

Figure 1: Yield of Pulp Produce versus Percent Charge of NaOH.
(Cooking time was 120 minutes and cooking
temperature was 160 °C)

Figure 1 showed that the maximum yield was achieved at 25 % which is around 28 %. The yield of pulp produced is increasing from 10 % chemical charge until 25 %, after 25 % the yield started decreasing. According to Biermann [3], the yield of pulp should be decreasing if the percentage of chemical increase. But this does not consider the reject which the fiber is not fully separated. A large amount of lignin is not remove and this will affect the paper quality.

A lot of reject was found at lower chemical charge of NaOH which is 10 % and 15 %. At 20 % chemical charge, the rejects in the pulp was dramatically reduced. At 25 % chemical charge, we achieved 28 % of the yield. After that, the yield of pulp was started to decrease when increasing the percent charge of NaOH. The yield of pulp is decreased to almost 13 % only when the concentration of NaOH used is 45 %. It is because the high concentration of NaOH not only decomposed the lignin but also decomposed the cellulose and holocellulose as well which are the major component of the pulp. The optimum yield 25 % obtained with 120 minutes cooking time and 160 °C. According to Cordeiro *et al*. [5], pulps with a yield of about 37-38 % were obtained when cooked in the presence of anthraquinone at 120 °C for a short cooking time of 30 minute.

The results of the experiments which varying the cooking time is shown in Figure 2. The result shows that the yields are increasing when the cooking time started to be increased from 30 minute to 90 minute. At 30 minute cooking period, the yield was less than 25 % but at 90 minute the yield was achieved around 30 %. After 90 minutes, the yield starts to decrease when continue to increase the cooking time. The percentage charge of NaOH is 20 % and the temperature is 160 °C. The cooking time from 30-90 minutes is the period for NaOH to attack lignin and to separate it from cellulose and hemicellulose. When the cooking time exceed 90 minutes, the NaOH starting to attack the cellulose and hemicellulose and this causes the lost of the yield. From the results obtained, the cooking time which needed to achieved high yield in this study is higher if compared to Cordeiro *et al*. [5] and from that research, they showed that there is no significant effect on the pulps yields when the cooking time continuous to increase after the optimum yield.

Figure 3 shown the result of the banana stem chips which were cooking with different cooking temperatures. The result shows that the

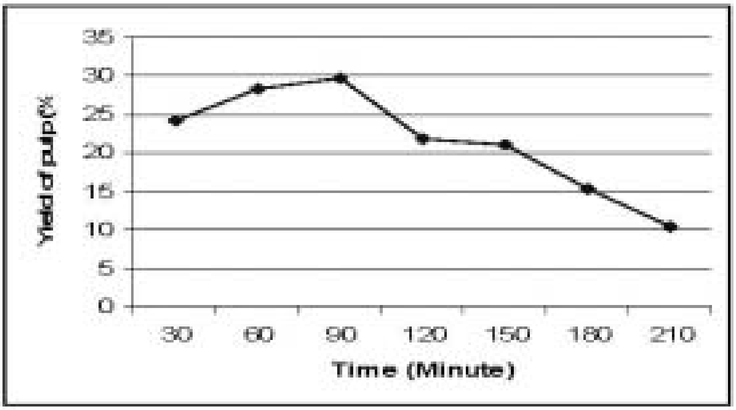

Figure 2: Yield of pulp produce versus cooking time of NaOH.
(Percent charge of NaOH was 20 % and cooking
temperature was 160 °C)

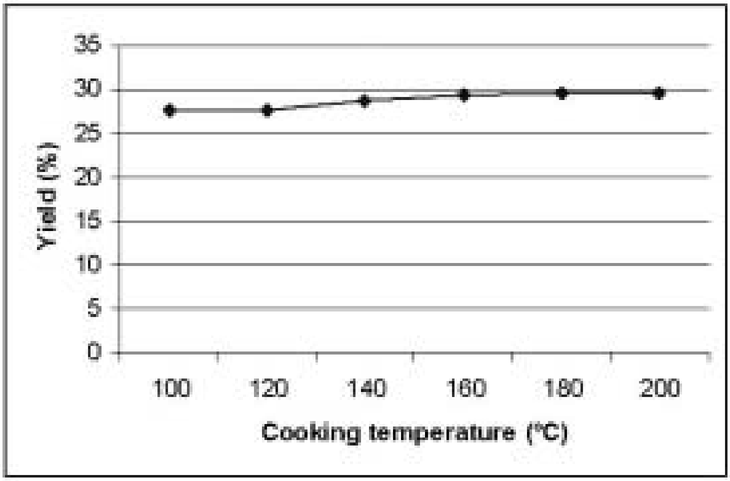

Figure 3: Yield of pulp produce versus cooking temperature of NaOH. (Percent charge of NaOH was 20 % and cooking time was 120 minutes)

effect of cooking temperature on the yield of pulp produced is not as significant as the other two variables discussed before.

The yield of the pulp which obtained from temperatures 100-140 °C is from 27-28 % and the maximum yield is obtained at 160 °C which is 29 % and maintained to be almost the same after that. The results obtained are similar to the earlier investigation [5].

Lignin is a macromolecule based on phenylpropane units, three-dimensionally cross-linked through various ether and C – C bonds. The dominant bonds are -and -arylether bonds. A large proportion of these bonds must be cleaved in the pulping process to achieve the fragmentation and subsequent dissolution of lignin. Phenylpropane units with free phenolic OH groups are very quickly attached. The initial step is the formation of a quinine methide structure, which already results in lignin degradation by cleavage of -arylether bonds. The OH ion can subsequently add to the quinine methide intermediate. It also could act as a strong nucleophile, which can initiate the cleavage of an arylether bound to a neighboring βC atom. Phenolate anions formed by this cleavage reaction favour the continued breakdown of lignin.

Even -arylether bonds in nonphenolic lignin units are cleaved, albeit more slowly, if an adjacent ionized hydroxyl group was originally present or were formed during the pulping reaction. Apart from the cleavage of arylether bonds, carbon-carbon bonds are also cleaved to some extent. The degradation of lignin by the pulping chemicals competes with condensation reactions caused by internal nucleophiles, expecially in the final phase of cooking. These reaction counteract further delignification by forming C – C bonds and greatly reduce the bleachability of the pulp produced [14].

The polysaccharides in the raw materials are also attacked and degraded under the conditions of alkaline pulping. The carbohydrate losses incurred and the reduction of the degree of polymerization are caused essentially by two reactions: the peeling reaction and alkaline hydrolysis. The former is primarily responsible for yield losses, while the later mainly causes a reduction of the chain length. The hemicelluloses are subject to degradation reactions because of their amorphous structure and their lower degree of polymerization. Galactoglucomannans and glucomannans are dissolved much faster than the fairly alkali resistant xylans [14].

The primary peeling reaction begins above 100 °C. In this process, sugar units are successively cleaved in a -alkoxy elimination reaction commencing at the reducing end of the carbohydrate chains. An average of 50-60 units are cleaved from the cellulose chain molecules until peeling is stopped by competing reactions and formation of an alkali stable carboxyl group at the end of the chain. Chain scission reactions occur at temperature above 150 °C due to alkaline hydrolysis, which lowers the degree of polymerization of cellulose. The ends of the chains, exposed by the hydrolytic cleavage of glycosidic bonds, are the starting point for the secondary peeling reaction. With increasing cooking time and more extensive lignin dissolution, the carbohydrate degradation reaction dominate and because of the reduced selectivity of the pulping reaction, cooking must be terminated to avoid excessive losses of yield and pulp strength [14].

Conclusion

The main objective of this study is to study the ease of pulping and yield of usable pulp from banana stems. The conclusion is the banana stem have a great potential to be an alternative raw material to wood base fibrous in pulping industry. The pulping process should be undergone with 25 % of concentration of NaOH, 90 minutes cooking time and 160 °C. The yield of the pulp in this research is about 30 %. We suggest that a continuous digester should be designed to increase the yield of the pulp. The quality of the pulp which produced from the banana stem is under investigation and will be reported shortly.

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