Carbohydrate Polymers 147 (2016) 133–138

Contents lists available at ScienceDirect

Carbohydrate Polymers

journal homepage: www.elsevier.com/locate/carbpol

Quality evaluation of dissolving pulp fabricated from banana plant stem and its potential for biorefinery

Atanu Kumar Das[a,b,c,*], Akiko Nakagawa-izumi[c], Hiroshi Ohi[b,c]

[a] PT. Indah Kiat Pulp & Paper Tbk. Perawang Mill, Indonesia
[b] Pulp and Paper Technology, Asian Institute of Technology, Thailand
[c] Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan

ARTICLE INFO

Article history:
Received 31 January 2016
Received in revised form 30 March 2016
Accepted 31 March 2016
Available online 4 April 2016

Keywords:
Musa sapientum
Alpha cellulose
Pre-hydrolysis liquor (PHL)
Biorefinery

ABSTRACT

The study was conducted to evaluate the quality of dissolving pulp of *Musa sapientum* L. (banana) plant stem and its potential for biorefinery. Introduction of pre-hydrolysis prior to any alkaline pulping process helps to reduce the content of hemicellulose and consequently produce acceptably high content of cellulose pulp. Water pre-hydrolysis was done at 150 °C for 90 min. The amount of lignin, xylan and glucan in the extracted pre-hydrolysis liquor (PHL) was 1.6, 4.9 and 1.6%, respectively. Pulping of pre-extracted chips was done following soda-AQ, alkaline sulfite and kraft process. The ratio of chip to liquor was 1:7 for both pre-hydrolysis and pulping. The kraft pulping process with 20% active alkali and 25% sulfidity at 150 °C for 90 min showed the best result. The lowest kappa number was 26.2 with a considerable pulp yield of 32.7%. The pulp was bleached by acidic $NaClO_2$ and the consistency was 10% based on air-dried pulp. The lowest amount of 7% $NaClO_2$ was used for the bleaching sequence of $D_0ED_1ED_2$. After $D_0ED_1ED_2$ bleaching, the pulp showed that α-cellulose, brightness and ash were 91.9, 77.9 and 1.6% respectively. The viscosity was 19.9 cP. Hence, there is a possibility to use banana plant stem as a raw material for dissolving grade pulp and other bioproducts.

1. Introduction

Pulp products like cellulose derivatives, viscose etc. and the most of paper pulp are extracted from wood. Forest is the majority source of wood. The production of wood pulp was 170 million tons whether it was 18.6 million tons for non-wood pulp. This pressure on forest causes destruction of forest rate 7,317,000 ha per year in the world. The deforestation is inciting global warming as well (FAO, 2005). By the time 1999–2003, the pulp extraction from non-wood enhanced by 10% and it was only 4% for wood fiber (Rodriguez, Serrano, Moral, Pérez, & Jiménez, 2008).

Replacing of petroleum products and reduction of emission of greenhouse gas through introducing biomass is the main growing research interest at present in the world. Ignition of fossil fuels contributes 7.0 billion tons of carbon/year in the atmosphere which is equivalent 82% of total greenhouse gas ejection (Chen, Lawoko, & van Heiningen, 2010). For this, the present pulp industry has given reasonable concentration for the production of biorefineries from forest products considering environmental problem and the necessity of biofuels and bioproducts (Ragauskas, Nagy, Kim, Eckert, & Liotta, 2006; van Heiningen, 2006). The concept of forest biorefinery in pulp mill is possible by the implication of pre-hydrolysis stage before pulping (Li, Lundquist, & Westermark, 2000; Richter, 1956).

Pre-hydrolysis separates the most of the hemicelluloses and dissolves a part of lignin (Liu, Fatehi, & Ni, 2011). This introduces converting polysaccharides into ethanol, butanol or other bioproducts (Mao, Genco, van Heiningen, & Pendse, 2010; Guo, Jia, Li, & Chen, 2010; Fitzpatrick, 2006).

Biermann (1996) and Hinck, Casebier, and Hamilton (1985) stated that kraft process and acid sulfite process are used for producing dissolving pulp from wood. It contains less than 0.05% lignin and above 90% cellulose. The final products of this pulp are cellulose ethers (carboxymethyl cellulose), cellophane and rayon, cellulose esters (acetates, nitrates, etc.), graft and cross-linked cellulose derivatives (Christov, Akhtar, & Prior, 1998).

The main important thing for choosing wood as a raw material for pulp is its chemical composition. Hardwood and softwood contain 40–44% cellulose (Desch & Dinwoodie, 1996). Some agricultural crops contain same amount of cellulose or more than that type of amount. Oil palm frond contains 49.8% α-cellulose while kenaf,

* Corresponding author at: QAP (Pulp Group), PT. Indah Kiat Pulp & Paper Tbk. Perawang Mill, Perawang 28772, Indonesia.
E-mail address: atanufwt03ku@yahoo.com (A.K. Das).

http://dx.doi.org/10.1016/j.carbpol.2016.03.103
0144-8617/

switchgrass and cotton contain >40% α-cellulose (Khalil, Alwani, & Omar, 2006; Ververis, Georghiou, Christodoulakis, Santas, & Santas, 2004). This thinking helps the scientists to use agricultural crops as a raw material for pulp and paper industry. There are more than 250, 000 known species of higher plants but experiment was conducted on 500 species only (Rowell, Young, & Rowell, 1997). Banana plant is one of the important agricultural crops.

Banana (*Musa sapientum* L.) is an herbaceous plant which is in *Musaceae* family (Anhwange, Ugye, & Nyiaatagher, 2009). Banana plant grows in tropical and subtropical areas (Khalil, Alwani, & Omar, 2006). Banana plants are 0.8 m to above 15 m in height (Ennos, Spatz, & Speck, 2000). Banana plant stem contains hollocellulose and α-cellulose 65.20 and 63.90%, respectively (Khalil, Alwani, & Omar, 2006). Its cellulose content and availability as annual renewable resource are an important consideration to use it as a raw material for pulp mills.

After collecting fruit the banana plant is thrown away or heaped up beside the cultivation land. It causes environmental pollution. Khalil, Alwani, and Omar (2006) have also mentioned that banana stem is not used for better purposes. Pulp made from banana plant stem may be well use of it. Using of banana plant stem as an alternative raw material may help to dissolve the problem of raw material partially for pulp mills. At the same time, it may also help to decrease dependency on others by reducing import of pulp from foreign countries.

The purpose of this study was to evaluate the extracted dissolving pulp of banana plant stem and its potential for biorefinery. Produced pulp and pre-extracted liquor were analyzed.

2. Materials and methods

2.1. Collection and preparation of raw material

Banana (*Musa sapientum* L.) plant stem was collected from the Laboratory field of Food Engineering and Bioprocess Technology, Asian Institute of Technology (Latitude-14°07/N and longitude-100°61/E), Thailand. The stem was dried in sunlight and it was made chip maintaining the dimension 2.5 cm × 1.25 cm for pre-hydrolysis and pulping as well. The particle size was 40 mesh pass for analysis of chemical components of raw material

2.2. Pre-hydrolysis

Water pre-hydrolysis was carried out in a mini-digester using oil bath. The ratio of chip to water was 1:7. The reaction time was 90 min whether temperature was 150 °C. The temperature was fixed from the previous study as the banana stem pulp showed the best performance at 150 °C (Das, Nakagawa-izumi, & Ohi, 2015). Considering the finding of best pulp properties at 150 °C, it was fixed for pre-hydrolysis. After pre-hydrolysis, the pre-hydrolyzed chip was pressurized to collect the total pre-hydrolysis liquor (PHL). The pre-hydrolyzed chip was then used for pulping. The pre-hydrolysis liquor (PHL) was freeze- dried. The yield (%) (Solid content) of PHL was determined on the oven dry weight basis.

2.3. Pulping

Pulping of pre-hydrolyzed banana plant stem chip was done by kraft, alkaline sulfite and soda-AQ pulping process. The active alkali and sulfidity for kraft pulping were 20 and 25%, respectively or 25 and 30%. The ratio of NaOH to Na_2SO_3 was 70 to 30 and the AQ dosage was 0.1% for alkaline sulfite pulping. The active alkali (as Na_2O) was 20% for alkaline sulfite pulping. In case of soda-AQ pulping, the active alkali was 25% and AQ dosage was 0.1%. The amount of NaOH and Na_2S was calculated based on Na_2O. The chip to liquor was 1:7. The temperature for each type of pulping was 150 °C. The pulping time was 30, 60 and 90 min for each type. The temperature was fixed from the previous study as the banana stem pulp showed the best performance at 150 °C (Das, Nakagawa-izumi, & Ohi, 2015). The pulp was washed properly to remove the residual chemicals after pulping. The total pulp yield was examined based on the basis of oven-dried weight of raw material (Table 1).

2.4. Disintegration of pulp

The pulp was disintegrated to separate the fiber after washing the pulp properly. It was disintegrated up to get totally separated fiber. It was noticed carefully so that there was no fiber bundles remain in the pulp.

2.5. Handsheet preparation

Handsheets were made using handsheet machine after disintegrating the pulp. The handsheet were dried in the air. The dried handsheets were kept in polyethylene bag to do further experiments.

2.6. Bleaching

Bleaching sequences for this study were $D_0D_1D_2D_3D_4$, $D_0D_1D_2D_3Ep$, D_0ED_1, D_0ED_1Ep, $D_0ED_1D_2Ep$ and $D_0ED_1ED_2$ (where D, E and p indicate $NaClO_2$, NaOH and H_2O_2). The amount of $NaClO_2$ for $D_0D_1D_2D_3D_4$, $D_0D_1D_2D_3Ep$, D_0ED_1, D_0ED_1Ep, $D_0ED_1D_2Ep$ and $D_0ED_1ED_2$ was 16, 16, 10, 10, 15 and 7%, respectively. $NaClO_2$ was applied on the basis of air-dried weight of pulp. The consistency was 10% in each stage for each type of sequence. Acetic acid was used to maintain the pH value 4.0 for D stage in every sequence. The temperature was 70 °C and reaction time was 60 min for every stage of each type of bleaching sequence. $Na_2S_2O_3$ was added except D_0ED_1 sequence before washing in the last stage of bleaching to remove the residual $NaClO_2$. The pulp was washed properly until neutralization in every stage. After bleaching handsheets were prepared and dried in the air for further uses.

2.7. Analysis

Acid-insoluble lignin of raw material, PHL and bleached pulp was examined using T 222 om-11. On the other hand, acid-soluble lignin was determined based on the method of UV–vis spectrometric at wavelength 205 nm (TAPPI um 250). Ash and extractive were determined using standard T 211 om-02 and T 204 om-88, respectively.

The sugar contents of raw material, PHL and bleached pulp were determined using Dionex ICS 3000 after acid hydrolysis using 72% sulfuric acid followed by 4% sulfuric acid. The acid hydrolysis was done at 120 °C for 1 h. Extractive free sample was used for raw material for acid hydrolysis. The analysis was done after filtering and diluting the samples. The flow rate of de-ionized water, 0.2 N NaOH and 0.5 N NaOH was 1, 1 and 1 mL/min, respectively. De-ionized water, 0.2 N NaOH and 0.5 N NaOH were used for this analysis as eluent, regeneration agent and supporting electrolyte, respectively.

2.8. Pulp evaluation

As TAPPI test method T525 om-92, the brightness was determined. Standard T 236 cm-85 was used for determining kappa number. The viscosity was measured following the standard T 230 om-89 and T 203 cm-99 standard was used for measuring α-cellulose.

The replication was two for each type of property except brightness. The total replication was 6 for the property of brightness. More