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Dissolving pulp from jute stick

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ABSTRACT

Jute stick is woody portion of jute plant, which remain as leftover after extracting bast fibre. Presently, it is being used for fencing in the rural area. In this investigation, biorefinery concept was initiated in producing dissolving pulp from jute stick by pre-hydrolysis kraft process. At 170 °C for 1 h of pre-hydrolysis, 70% of hemicelluloses was dissolved with negligible loss of α-cellulose. At this condition, 75% of dissolved sugars in the pre-hydrolysis liquor were in the oligomeric form. The pre-hydrolysed jute stick was subsequently pulped by kraft process with the variation of active alkali. The pulp yield was 36.2% with kappa number 18.5 at the conditions of 16% active alkali for 2 h of cooking at 170 °C. Final pulp was produced with 92% α-cellulose and 89% brightness after $D_0E_pD_1EpD_1$ bleaching. The produced dissolving pulp can be used in rayon production.

1. Introduction

Jute stick is the woody portion of jute plants remain as leftover after extracting fibre (Pandey, Ghosh, & Dey, 1995). It constitutes about 2.5 times of extracted fibre. Jute sticks are used as fuel wood, fencing in the rural area. Jute stick contains considerable amount of cellulose with lignin and hemicelluloses. Therefore, it is a potential source for a biorefinery.

There has been a scarcity of lignocellulosic materials for production of pulp and paper products in Bangladesh. Because of depletion of forest resources interest is growing on alternative lignocelluloses. Jute stick falls under the category of hardwood and the annual production of jute sticks in the country is around 3.0 million tonnes (IJSG, 2014, http://jute.org/statistics_search.php).

Many studies have been carried out on utilization of jute stick. Its lignin, hemicelluloses and cellulose were used in different biobased products. Roy, Sardar & Sen (1989) studied on lignin isolated from spent soda liquor of jute stick pulping process, which was used for the preparation of lignin phenol formaldehyde resins. It was observed that phenol in phenol formaldehyde resin could be replaced up to a maximum of 50% by jute stick soda lignin. The feasibility of utilizing jute sticks in terms of quality, availability and economics of paper manufacture in the paper industry was studied by Das (1980) and showed economically viable for Indian paper pulp plant. Das, Day & Pandey (1987) prepared a variety of boards from jute stick, usable purpose such as in furniture, table tops, building materials, partitioning materials, false ceilings, etc. Day, Chattopadhay, Ghosh & Bhaduri (2007) used jute stick for producing high purity cellulose pulp by pre-hydrolysis followed by Kraft process and obtained 93% cellulose. Subsequently, this CMC and MCC were produced from this pulp. At suitable condition jute stick was carbonized to give, in good yield, a light-weight, smokeless, charcoal in chip form with high fixed-carbon content (Banerjee & Mathew, 1985).

Considering the depleting of petroleum resources and global warming importance have been increased towards efficient biorefinery technology to convert lignocelluloses to biofuels, biochemicals (Cheng & Zhu, 2009). Dissolving pulp production process well fit with the biorefinery, where lignocelluloses are fractionates to cellulose pulp and hemicelluloses (Saeed et al., 2012). Dissolving pulp is of also critical importance as a sustainable feedstock for manufacturing various materials such as, cellulose derivatives, nano-/micro-cellulose, which are alternatives to many petroleum-based materials. In recent years, the production of dissolving pulp experienced a significant increase owing to the strong growth of market demand. Dissolving pulp has special properties, such as a high level of purity, uniform molecular-weight distribution and the reactivity and accessibility of cellulose to chemicals (Krässig, 1993). To achieve maximum purity of pulp single or multiple pretreatment of auto hydrolysis, acid hydrolysis, mechanical and swelling treatments, enzyme treatment etc. need to be done (Engström,

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Monica, & Henriksson, 2006). The pre-hydrolysis kraft process is a well-known process for dissolving pulp production (Sixta, 2006). The auto-hydrolysis of wood prior to pulping is carried out in order to dissolve hemicelluloses. During auto-hydrolysis of wood, chips acetic acid is formed directly from the cleavage of acetyl groups of the xylan backbone, which easily impregnates and hydrolysis uniformly. The fact that hemicelluloses are considerably easier to hydrolyse than cellulose, which means selectively removing hemicelluloses. The presence of sulphuric acid in the pre-hydrolysis process enhances the removal of hemicelluloses from the lignocellulosic materials (Jahan, 2009; Liu et al., 2009). Acid pre-hydrolysis is also carried for total hydrolysis of lignocellulosic biomass to sugar monomers, which is a novel source of chemicals (Grethlein & Converse, 1991). In mechanical pulping acid prehydrolysis is applied in order to soften the wood structure and therefore save refining energy (Kenealy, Horn & Houtman, 2007). But it was observed that the acid pre-hydrolysis attacked cellulose in the dissolving pulp production process (Jahan, 2009). Considering the above discussion, hot water pre-hydrolysis is chosen for dissolving pulp production. In the pre-hydrolysis process most of the hemicelluloses are dissolved, which can be used in biofuel and biochemicals. The α-cellulose, hemicelluloses and lignin content in jute stick are similar to hardwood. Therefore, it can be a good source for dissolving pulp-based biorefinery.

Jute stick is a very important lignocellulosic raw material in Bangladesh. But no study has been carried out on jute stick for dissolving pulp using biorefinery concept. Therefore, the objective of this study was to pre-hydrolyse jute stick by varying time and temperature with respect to maximum dissolution of hemicelluloses and minimum attack on cellulose. Subsequently, optimized pre-hydrolysed jute stick was cooked and bleached for producing dissolving pulp. The pre-hydrolysis liquor (PHL) of jute stick was also assessed to produce biofuels and biochemicals.

2. Materials and methods

2.1. Raw materials

Jute stick was collected from the Jute Research Institute, Dhaka and cut to 2–3 cm in length. After determination of the moisture content, air-dried raw material equivalent to 200 g o.d. (oven dried) material was weighed separately in polyethylene bags for subsequent pre-hydrolysis and cooking experiments. Jute stick contains about 39% α-cellulose, 18% hemicelluloses and 25% lignin with other minor ingredients.

2.2. Pre-hydrolysis

Pre-hydrolysis was carried out in an electrically heated digester of 5 L capacity. The digester was rotated at 1 rpm. Water pre-hydrolysis was carried out at 150, 160 and 170 °C for 60, 90 and 120 min. The raw material to liquor ratio was 1:5 (g/mL). The time required to raise max temperature from room temperature (30 °C) was 35 min. After completing pre-hydrolysis, pressure was released by venting the valve and the liquor was separated from the solid mass by filtration and kept in refrigerator for analysis.

2.3. Solid contents

The total solid content in the PHL was determined gravimetrically by drying 10 ml sample at 105 °C till to constant weight.

2.4. Lignin analysis

The dissolved lignin in the pre-hydrolysate was measured based on the UV/vis spectrometric method at wavelength 205 nm (TAPPI UM 250).

2.5. Sugar analysis

PHL was filtered to remove any solid particle with filter paper. A vial containing 1 mL of the PHL and 4 mL 4 N sulfuric acid was sealed and autoclaved at 121 °C for 60 min. Component sugars and organic acids were analyzed by high-performance liquid chromatography (HPLC) equipped with refractive index and UV detection (Shimadzu, Columbia, MD), using the Aminex HPX-87H column (Bio-Rad, Hercules, CA). The column was operated with a 5 mM sulfuric acid mobile phase at a flow rate of 0.6 mL/min and oven temperature of 60 °C. Samples were filtered through 0.22 μm syringe filters prior to injection. The sugar contents in oligomeric form in the pre-hydrolysis liquor were calculated from the difference of the monomeric sugar contents between pre and post hydrolysis PHL.

2.6. Pulping

Pulping of pre-hydrolysed jute stick (at 160 °C for 90 min) by the kraft process was done in the same digester as in pre-hydrolysis under following identical cooking conditions. These were:

- Fibre to liquor ratio: 1:5 g/mL.
- Active alkali charge: 14, 16, 18% on pre-hydrolysed residue.
- Sulphidity: 27%
- Temperature: 170 °C.
- Cooking time: 120 min at maximum temperature.

2.7. $D_0EpD_1EpD_2$ bleaching

Pulps were bleached by D_0EpD_1 bleaching sequences in plastic bag. In the first stage (D_0) of $D_0EpD_1EpD_2$ bleaching sequences ClO_2 charge was 2%. The initial pH was adjusted to 2.5 by adding dilute H_2SO_4. In the alkaline extraction stage, NaOH and H_2O_2 charge were 2% and 0.5% (on o.d. pulp), respectively. The temperature was 70 °C for 60 min and pulp consistency was 10%. In the D_1 stage, the end pH was 4. The ClO_2 charge in the D_1 was 1.0%. In the D_2 stage, ClO_2 charge was 0.5% and end pH was maintained to 6.0 by adding weak alkali.

2.8. Evaluation of pulps

Pulp tests were performed according to the Standard Methods of the Technical Association of the Pulp and Paper Industry (TAPPI, Atlanta, GA): kappa number (T 236 cm-85); brightness (T 452 om-92); viscosity (T 230 om-89), α-cellulose (T 203 om-88) and alkali solubility S_{10} and S_{18} (T 235 cm-85).

3. Results and discussion

3.1. Pre-hydrolysis

In this study jute stick was pre-hydrolysed with varying time and temperature to get maximum dissolution of hemicelluloses without affecting cellulose. Effect of pre-hydrolysis conditions on solid yield and the liquor composition from jute stick have been listed in Table 1. Solid yield was in the range of 72–89% depending of time and temperature. A sharp decrease in solid yield was observed with rising temperature, which was attributed to both extractive removal and hemicelluloses solubilization (Yánez, Romanií,