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Dissolving pulp production from sugar cane bagasse

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ABSTRACT

The main goal of this study was characterizing the sugar cane bagasse two main fractions: pith and depithed bagasse, and evaluating the potential of the depithed for production of dissolving grade pulps. The depithed bagasse was chemically characterized and converted into brown pulp of two different extents of delignification degrees (kappa 16.9 and 9.2) by the pre-hydrolysis soda process, which consists of bagasse treatment with hot water (15 min at 180 °C) followed by conventional soda pulping. The resulting pulps were fully bleached by the O-D-(EP)-D-P sequence and evaluated for their main dissolving pulp characteristics. The contents of cellulose, hemicelluloses and lignin in the pith and depithed bagasse varied significantly. For example, the lignin S:G:H of the pith and depithed bagasse were 1.0:1.6:1.8 and 1.0:2.1:2.0, respectively. The pre-hydrolysis pretreatment terminated at pH 3.4 and removed 29% of the depithed bagasse weight. The pre-hydrolysis soda process improves the xylan removal but decreases pulp yield. The bleached pulps showed similar glucans (~95%), xylans (~5.0%), ash (~0.4%), silica (~0.15%) and α-cellulose content (~92%) regardless of kappa number. The low viscosity values and the high ash and silica contents limit the uses of the bagasse pulps for certain dissolving grades applications, but it is useful for production of viscose rayon and CMC derivatives after some demineralization. The elucidation of the pith lignin S:G:H ratio and the production of high yield (35.1%) dissolving pulp from depithed bagasse fraction without bleaching cost penalties are the main novelties of this paper.

1. Introduction

In recent years, there has been an increasing trend toward more efficient utilization of agro-industrial residues, including sugar cane bagasse. Several processes and products have been reported that utilize sugar cane bagasse as a raw material. These include production of dissolving pulp, paper pulp, ethanol and power (Pandey et al., 2000).

The sugar cane (*Saccharum officinarum*) is a perennial grass, originating from Asia, but well adapted in most tropical and subtropical climates. Brazil is the largest producer of sugar cane in the world, followed by China, India, Thailand and Australia. In 2011/12, Brazil produced 571 million tons of sugar cane on 8.4 million ha of land, with an average productivity of 68 tons/ha (Conab, 2012). About 50.3% of this production was used to manufacture ethanol (22.9 billion liters), 47.3% to make sugar (36.9 million tons) and 2.4% was used to produce alcoholic beverages/candies (Conab, 2012). Wastes from sugar cane agro-industry are produced in large quantities. Hence about 140 kg of bagasse on a dry weight basis (CTC, 2012). This way, about 80 million tons of bagasse is generated per year in 8.4 million ha of land (Conab, 2012).

Bagasse consists of approximately 40–50% cellulose and 20–30% of hemicelluloses and 18–25% lignin. Xylose is the main carbohydrate found in the hemicellulose fraction, representing about 80% of total sugars from hemicellulose (Aguilar et al., 2002; Mosier et al., 2005). Because of its low ash content (1–3%), bagasse offers numerous advantages in comparison to other crop residues such as rice straw and wheat straw, which contain ~17 and 11.0% of ash, respectively (Pandey et al., 2000).

Sugar cane bagasse is a lignocellulosic material with potential for dissolving pulp production, especially when integrated into biorefinery processes (Wolf, 2011). Dissolving pulps require a high degree of purity and are used for production of cellulose derivatives such as cellulose nitrate, cellulose acetate, methyl cellulose, rayon, carboxymethylcellulose among others. Compared to other types of paper pulp, dissolving pulp contains very little or no lignin, low hemicellulose content and very low levels of degraded cellulose.

There are different requirements of alpha cellulose content for different final uses of the dissolving pulp. According to Wizani et al. (1994), the desired alpha cellulose contents for rayon/cellophane, cellulose acetate and nitrocellulose are 90–92, 95–97 and 98%, respectively. All these derivatives require pulps containing very low or no lignin, low hemicelluloses and very low degraded cellulose.

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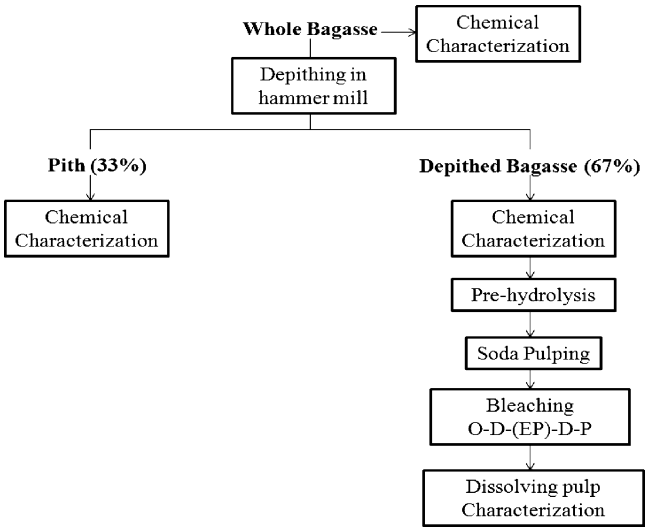

Fig. 1. Working plan for bagasse fractionation, characterization and dissolving pulp production using the pre-hydrolysis soda process.

According to Dhamodaram (2003), the chain-like high molecular weight cellulose polymer can be transformed into fibers or films of desired properties by spinning, casting, rolling, or extruding, from a melt or from solution. The natural and renewable cellulose polymer frequently occurs as fibers that are too short for textile uses. It cannot however be converted directly into longer fibers or into film because it can neither be melted nor simply dissolved in a solvent owing to strong hydrogen bonding in the material. A suitable cellulose derivative must first be prepared before it is possible to form a spinning solution from which cellulose can be regenerated. The commercially used systems for this purpose are the viscose process, to a lesser extent the cuprammonium and acetate process.

Soda pulping is traditionally the most used chemical pulping process for various non-wood raw materials including bagasse (Khristova et al., 2006; Enayati et al., 2009). The introduction of auto-hydrolysis (pre-hydrolysis) prior to any alkaline pulping process helps to produce pulp with a satisfactorily high content of alpha cellulose and with low hemicelluloses content (Behin and Zeyghami, 2009).

The novelty of this paper is the thorough chemical evaluation of the sugar cane bagasse pith fraction including lignin S:G:H ratio, which to the best of our knowledge has never being published. Also, the demonstration of the feasibility of producing high yield (35.1%) dissolving pulp from depithed bagasse fraction of sugar cane bagasse by terminating the cook at a kappa number higher than usual (kappa ~17) without significant penalty in bleaching cost.

The main goal of this study was characterizing the sugar cane bagasse two main fractions (pith and fibers), and evaluating the potential of the fibers for production of dissolving grade pulps.

2. Experimental

2.1. Working plan

Fig. 1 depicts the working plan. The two fractions of the sugar cane bagasse (pith and fibers) were separated in a hammer mill and were characterized chemically. The whole bagasse was also characterized. The depithed bagasse fraction (fibers) was converted into brown pulp of two different delignification degrees (kappa 16.9 and 9.2) by the pre-hydrolysis soda process. The resulting pulps were fully bleached by the O-D-(EP)-D-P sequence and evaluated for their main dissolving pulp characteristics.

2.2. Material

About 150 kg of industrial whole bagasse was provided by a Brazilian pulp mill. About 100 kg of the whole bagasse was separated into two fractions (pith and depithed bagasse) by a hammer mill. The pith fraction represented 33% while the other 67% remained as depithed bagasse. The pith, depithed bagasse and whole bagasse were dried to about 85% dryness in an acclimated room (23.0 ± 1.0 °C and 50.0 ± 2.0% moisture) and stored in polyethylene bags for further use. The air-dried samples of pith, depithed bagasse and whole bagasse were ground in a Wiley mill, sieved, and the fraction that passed through a 40 mesh screen and was retained in the 60 mesh screen was collected, air dried and stored in wide mouth sealed flasks.

2.3. Methods

2.3.1. Chemical characterization of pith, depithed bagasse and whole bagasse

The following procedures were used for chemical analysis: moisture content (TAPPIT 264 om-88), total extractives content (TAPPIT 264 cm-97), acid soluble lignin (Goldschinid, 1971), Klason lignin (Gomide and Demuner, 1986), lignin syringyl/guaiacyl ratio (Lin and Dence, 1992), preparation of biomass for sugar analysis (TAPPI T 249 cm-85), sugar analysis (Wallis et al., 1996), acetyl groups (Solar et al., 1987), uronic acids (Scott, 1979), silica (TAPPI T 245 cm-98) and ash (TAPPI 211 om-93).

2.3.2. Pre-hydrolysis of the depithed bagasse

The pre-hydrolysis of the depithed bagasse was carried out in a M/K digester (Systems Inc., MA, USA) with a capacity of 7 l, equipped with forced circulation and heat exchanger devices. It was conducted using the following parameters: ratio of water/biomass 8:1 l/kg, temperature 180 °C, 60 min to temperature and reaction time of 15 min at temperature. The pre-hydrolysis experiments were carried out according to Colodette et al. (2011). Optimal conditions were identified for the various raw materials on the basis of yield, xylans removal and cellulose molecular weight. Note that the bagasse samples were not washed after the pre-hydrolysis treatment; they were immediately treated with the soda pulping process. The following procedures were used for analysis of the pre-hydrolyzed material: total extractives content (TAPPI T 264 cm-97), acid soluble lignin (Goldschinid, 1971), Klason lignin (Gomide and Demuner, 1986), lignin syringyl/guaiacyl ratio (Lin and Dence, 1992), preparation of biomass for sugar analysis (TAPPI T 249 cm-85), sugar analysis (Wallis et al., 1996), acetyl groups (Solar et al., 1987), uronic acids (Scott, 1979), silica (TAPPI T 245 cm-98) and ash (TAPPI 211 om-93).

2.3.3. Soda pulping

The soda pulping of the depithed bagasse was carried out in the same equipment used for the pre-hydrolysis treatment, aimed at producing pulps with two different delignification degrees (16.9 and 9.2), using the following parameters: ratio of liquor/biomass 8:1 l/kg, maximum temperature 180 °C, time to maximum temperature of 60 min, time at maximum temperature of 20 min, and 12.5 and 15.0% alkali charges, to reach kappa number 16.9 and 9.2, respectively.

After cooking, the chips were placed in stainless steel screen box of 150 mesh and were washed thoroughly with running water. The disintegration of the fibers was performed in a laboratorial "hydrapulper" of 25 l capacity. The pulp was classified in a "Voith"