Potassium hydroxide based biorefinery concepts for non-wood bioresources

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The paper and paperboard production in 2016 in the world was 110.07 million tones. Bangladesh consumes only about 3.5–4 kg paper and board products per capita, while the developed countries consume about 300 kg/capita. Bangladesh’s consumption is also much lower than the world’s average (±50 kg/capita) and the Asia’s average (±50 kg/capita). To reach the world’s or Asia’s level, Bangladesh’s consumption of paper and board products needs to increase 10 folds. As forest resources are very limited in Bangladesh, alternative fibrous raw materials are required to achieve this goal. Therefore many studies have been carried out on alternative raw materials available in Bangladesh.3-5

Bangladesh is one of the most populous countries in the world, 1,252 people per square kilometer.6 As of 2016, agriculture contributes 14.78% of the country’s GDP.7 Rice straws are the most abundant agricultural waste (78.3 million MT), followed by wheat straws (2 million MT) in Bangladesh.8 Other agricultural wastes include bagasse (1.5 million MT) and maize stalks (1.5 million MT).8 These agricultural wastes can be alternative fiber sources for pulping, although the amount of agricultural wastes generated in a region of Bangladesh may not be sufficient to feed a conventional kraft or soda pulp mill of economic size.

Traditionally non-wood raw materials (e.g. agricultural wastes) are cooked by the conventional soda and kraft pulping processes. Most of the agricultural wastes contain high amount of silica.9,10 The main drawback is the dissolution of silica in the spent liquor, which causes severe scaling problem in the chemical recovery process. To overcome these problems, many new pulping technologies have been studied. In the organic acid pulping, the major portion of silica remains on the fibers, therefore, spent liquor recovery problem would be solved.11,12 Silica retained on the pulp fiber can be dissolved by alkaline extraction; subsequently silica can be separated from the alkaline extracted liquor by reducing pH to 7 and used for industrial purposes.10 Huang et al.13,14 discovered wheat straw pulping without generating black liquor waste by using aqueous ammonia mixed with a small amount of potassium hydroxide (KOH), which enriched the black liquor with nutrients such as potassium and nitrogen as a fertilizer. Sun et al.15 also reported the use of KOH and NH₃OH for corn stover pulping with approximately a 90% delignification rate at 150 °C for 30 min. Dissolved silica can be precipitated from the alkaline spent liquor by neutralizing the pH to 7.10 Toledano et al.16 showed that lignin could be recovered from black liquor; Ahsan et al.17 reported that nanofiltration could concentrate hemicellulosic sugars from solutions. After the separation of silica and dissolved biomass, potassium rich liquor can be used for agricultural irrigation purposes. Silica itself is an essential component of materials which have many uses in industry and are a vital component in many things used in our everyday lives.

Scheme 1: Potassium hydroxide pulping for the biorefinery of non-wood bioresources

Scheme 1 shows the concept of KOH based non-wood biorefinery. Fibers are extracted from rice or wheat straws to make pulp for papermaking. Dissolved saccharides, lignin and silica can be separated from the spent liquor for value added products. The residual spent liquor which is rich in potassium and organics can be used as fertilizer and soil amendment. In a study of KOH pulping of rice straws and wheat straws, 42.4% yield with a kappa number of 10.8 and 48.0% yield with a kappa number of 16.1 were achieved, respectively, under the conditions of 12.8% NaOH, solid to liquid ratio of 1:6, 150°C and 2 hrs. The pulp was bleached to 81-84% ISO brightness with a D0EpD1 bleaching sequence and 25 kg/ton ClO₂ consumption.18 In
another study of KOH pulping process, the pulp yield was 48.6% and 46.3%, and the kappa number was 7.4 and 12.3, for kash and bagasse, respectively, at the conditions of 16% alkali charge (as NaOH), 150°C and 120 min. During the KOH pulping process, silica and part of biomass are dissolved which can be exploited into bio-based products. Silica was separated from the black liquor of rice straw pulping by reducing the pH to 7 with dilute sulfuric acid addition and carbon dioxide bubbling. The yield of silica separated from the black liquor of the KOH pulping process was 8.6% to 10.4%, based on the raw materials.

The black liquor contains organic C, which was mostly derived from polysaccharides and lignin, suggesting that black liquor may have potential as a soil amendment. Application of black liquor increased plant nutrients. It has been reported that the cation exchange capacity (CEC) of soil increased 42% with the application of black liquor. Available K in black liquor applied soil was increased to 414.3 µg/g soil from 77.3 µg/g soil in the control soil. Xiao found that a satisfactory pulp as well as a high value of potassium based fertilizer could be obtained when the sodium is substituted by potassium in kraft pulping. The nitrogen (N), phosphorus (P) and sulphur (S) contents in soil increased with the amendment of soil by black liquor, which was advantageous for plant growth.

The spent liquor from KOH pulping has been reported to increase the yield of Red amaranthus. The plant weight increased to 123.45 g/pot from 45.4 g/pot with the application of black liquor. In addition to K, black liquor contained organics, which improved soil quality and increased growth. The plant height and shoot weight were also increased with applying black liquor. The shoot weight increased from 6.78g/pot to 17.67 g/pot by soil amendment with PL, while RF with PL increased shoot weight to 20.56 g/pot.

Therefore, KOH based pulping processes can overcome the silica related scaling problems encountered in conventional kraft and soda pulping of non-wood fibrous raw materials. In addition, a KOH-based pulp mill can be easily integrated into a biorefinery with rice/wheat straws as the feedstock, and the effluent from the mill can be used as fertilizer and for soil amendment.

REFERENCES