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Review

Valorization of solid waste in sugar factories with possible applications in India : A review

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ABSTRACT

Sugar production is a major agro-based industry in India that generates various solid wastes viz. sugarcane trash, bagasse, press mud and bagasse fly ash. This work examines the state-of-the-art in innovative value added products that can be obtained from the transformation of these wastes. Challenges in implementing these waste valorization solutions are also highlighted. It is observed that the extent of research and adoption of these solutions vary considerably. Both industry involvement as well as government encouragement is required in translating the research findings into commercial products.

1. Introduction

India is one of the largest growers of sugarcane with an estimated production of around 300 million tons in the marketing year 2009–10 (Singh, 2009). Sugar-distillery complexes, integrating the production of cane sugar and ethanol, constitute one of the key agro-based industries. There are presently nearly 500 sugar factories in the country along with around 300 molasses based alcohol distilleries (Indiastat, 2010; Tewari et al., 2007). Fig. 1 depicts the process details and the major solid waste streams generated in the sugar manufacturing process. These include sugarcane trash, bagasse, press mud and bagasse fly ash. The key characteristics of these solid wastes and the approach used for their management are summarized below.

- *Sugarcane trash*: This refers to the leaves, tops etc. that are obtained upon sugarcane harvesting. This is a lignocellulosic material with an approximate composition of 40% cellulose, 25% hemicellulose and 18–20% lignin. About 0.09–0.11 ton trash is generated per ton of sugarcane harvested (Singh et al., 2008a). The trash is conventionally disposed off by burning in the fields.
- *Bagasse*: This is the fibrous residue obtained from sugarcane juice extraction and consists of cellulose (50%), hemicellulose (25%) and lignin (25%) (Ezhumalai and Thangavelu, 2010; Abhilash and Singh, 2008). About 0.25–0.30 tons bagasse is produced per ton of sugarcane (Pessoa et al., 1997). It has a calorific value of 8021 kJ/kg and is commonly used as a fuel in boilers to generate steam and electricity through cogeneration (Babu and Ramakrishna, 1998). Other applications include use as a raw material in agro-residue based pulp and paper mills.
- *Bagasse fly ash*: This is the waste generated by the combustion of bagasse. Apart from silica which is the major component, it contains other metal oxides as well as unburned carbon (Table 1) (Umamaheswaran and Batra, 2008). Around 0.005–0.066 tons fly ash (without the carbon) is generated per ton of sugarcane crushed (Iyer et al., 2002). This waste is typically disposed off in pits; it is also applied on land for soil amendment in some areas. Approximately 0.97 million tonnes of unburned carbon is available from bagasse fly ash alone in India.
- *Press mud*: This is the solid residue obtained in the sugarcane juice clarification process. It is a complex product containing crude wax (5–14%), fiber (15–30%), crude protein (5–15%), sugar (5–15%), SiO (4–10%), CaO (1–4%), PO (1–3%), MgO (0.5–1.5%) and total ash (9–10%) (Partha and Sivasubramanian, 2006). The estimated generation is 0.03 ton per ton cane

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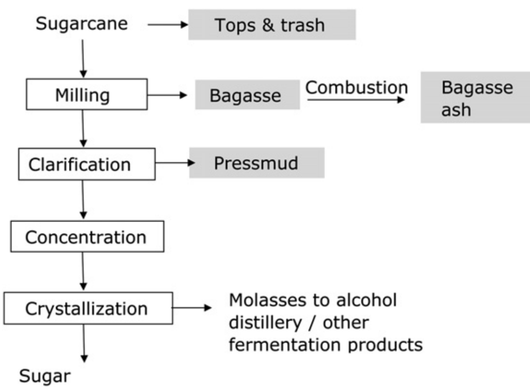

Fig. 1. Solid wastes generated in cane sugar production.

processed (Yadav and Solomon, 2006). Press mud is typically disposed off by direct application to land as a fertilizer; it is also used as filler for biocomposting with distillery spentwash.

Not all the waste management approaches used in the sugar-manufacturing sector are environment friendly. For instance, disposal of bagasse fly ash by dumping is not attractive because of the large land area requirement and pollution concerns due to air-borne particulate matter. Further, because of the presence of unburned carbon, these dumps are prone to catch fire spontaneously; as such, they need to be regularly sprinkled with water. The practice of burning sugarcane trash is yet another contributor to air pollution.

With this background, the aim of this manuscript is to examine innovative value added products that can be obtained from the transformation of sugar industry wastes. Such initiatives, in turn, are expected to promote alternative approaches to waste management in this sector. The concept of industries based on sugarcane by-products has been examined earlier (Yadav and Solomon, 2006). This work presents the state-of-the-art in this field especially focusing on high value products and their applications. Challenges in adopting these waste valorization solutions are also highlighted.

2. Products from sugarcane trash and bagasse

2.1. Fuels and chemicals

Combustion of bagasse in boilers for steam and electricity generation is commonly used in sugar mills. To improve energy recovery, a combination of bagasse and sugarcane trash has been investigated as a fuel in biomass integrated-gasifier/gas turbine combined cycle (BIG/GTCC) operations. This has been especially advocated in sugarcane producing countries like Cuba and Brazil (Larson et al., 2001). Supplementing bagasse with trash is reported to enhance electricity generation by 500% (UNDP, 2007); however, the presence of alkali metals (Na and K) in the resulting producer gas is detrimental to the gas turbine blades (Gabra et al., 2001). Though extensive work has been done on this topic, no commercial BIG/GT system is reportedly operational (Leal, 2009; IEA, 2007). The developments are mostly taking place in the developing countries and the technology needs to be adapted to conditions in sugar manufacturing countries (Leal, 2009). Other factors such as feed availability (competition with other user industries), logistics of supply and cost also need to be considered.

Table 1
Composition of bagasse fly ash (Umamaheswaran and Batra, 2008).

Compound	% Weight
SiO_2	65.03
Al_2O_3	0.49
Fe_2O_3	0.49
TiO_2	0.08
P_2O_5	1.14
CaO	2.75
MgO	3.26
Na_2O	0.06
K_2O	1.73
Cl	0.12
MnO	0
SO_3	0
Loss on Ignition	24.84

The production of fuel ethanol from bagasse is another major application. Dedini SA, Brazil has reported industrial scale production of ethanol from bagasse using an efficient pre-treatment method involving organic solvents and dilute acid hydrolysis (Biopact, 2007). In another initiative, a 3 ML/year bagasse based ethanol plant was commissioned in Thailand using the dilute acid steam explosion pre-treatment process (Johnson et al., 2010). However, reduction in operation costs still remains a challenge in this application; as such, extensive research on various pre-treatment methods are still underway (Zheng et al., 2009). This application has seen active industry participation as a result of high interest in renewable fuels and their anticipated market. This, in turn, has contributed towards joint research and scale-up.

Unlike bagasse that is available in the sugar mill, sugarcane trash is dispersed in the fields. Thus an effective collection mechanism is required if trash is to be employed in the sugar factory for cogeneration. Alternatively, decentralized options such as conversion of trash into charcoal powder and briquette can be explored. Charcoal making kilns developed by Appropriate Rural Technology Institute of India (ARTI) have been installed in sugarcane fields and the resulting charcoal/briquettes can be used as fuel in domestic stoves (ARTI, 2007). Making of charcoal briquettes from sugarcane trash is being taken up in certain areas of Tamil Nadu in southern India (The Hindu, 2010). Yet another option is trash mulching with dry leaves and also the lower green leaves. The use of sugarcane trash mulch reportedly improves soil properties, water use efficiency and nutrient uptake (Mahimairaja et al., 2008; Ram et al., 2006); it also increases the yield of crops like groundnut and castor (TNAU, 2003) and assists in weed control (iKisan, 2000).

In addition to fuels like ethanol, bagasse has been investigated as a starting material for the production of chemicals (Pandey et al., 2000). The cellulose/hemicellulose fractions have been modified for products like biodegradable plastics (Shaikh et al., 2009), adhesives (Vieira et al., 2009) etc. The bagasse has also been used as a source of cellulose whiskers (de Morais Teixeira et al., 2011; Bhattacharya et al., 2008); such whiskers have considerable potential in reinforcing composites (La Mantia and Morreale, 2011; Satyanarayana et al., 2009). The lignin component has been used as a phenol substitute in phenolic molded-type resins (Piccolo et al., 1997; Hoareau et al., 2006), as a pesticide for insect pests (Khanam et al., 2006) and for making nanostructured films for heavy metal adsorption (Pereira et al., 2007). The driver here is the shift from petroleum based raw materials towards renewable biomass resources for chemicals production (biorefining). This is another application where industry participation in joint research with universities exists (e.g. Lane, 2010) and is expected to contribute towards scale up and commercialization.

2.2. Adsorbents

Bagasse has been explored as a low cost adsorbent for pollutant removal from aqueous streams. In addition to as-received bagasse,