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Pervaporation of ethanol produced from banana waste

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ABSTRACT

Banana waste has the potential to produce ethanol with a low-cost and sustainable production method. The present work seeks to evaluate the separation of ethanol produced from banana waste (rejected fruit) using pervaporation with different operating conditions. Tests were carried out with model solutions and broth with commercial hollow hydrophobic polydimethylsiloxane membranes. It was observed that pervaporation performance for ethanol/water binary mixtures was strongly dependent on the feed concentration and operating temperature with ethanol concentrations of 1–10%; that an increase of feed flow rate can enhance the permeation rate of ethanol with the water remaining at almost the same value; that water and ethanol fluxes was increased with the temperature increase; and that the higher effect in flux increase was observed when the vapor pressure in the permeate stream was close to the ethanol vapor pressure. Better results were obtained with fermentation broth than with model solutions, indicated by the permeance and membrane selectivity. This could be attributed to by-products present in the multicomponent mixtures, facilitating the ethanol permeability. By-products analyses show that the presence of lactic acid increased the hydrophilicity of the membrane. Based on this, we believe that pervaporation with hollow membrane of ethanol produced from banana waste is indeed a technology with the potential to be applied.

1. Introduction

One of the bases for the economic development of Brazil is agriculture, and in certain states, such as Santa Catarina, banana is widely cultivated as a commercial crop. Banana is one of the most consumed fruits in the world and it is commercially grown in about 120 countries. Currently, Brazil is the second largest producer (preceded by India) and is responsible for 7.5% of world production (about 7.2 million tons per annum, according to the Center of Socioeconomics and Agricultural Planning for the State of Santa Catarina). The State of Santa Catarina has approximately six thousand producers, being the fourth largest banana growing region in Brazil, with 663,892 tonnes of bunches of bananas produced per annum (ABIB, 2011).

Commercial banana production generates a large proportion of waste; there are reports of 30% waste in Australia (Clarke et al., 2008) and Malaysia (Tock et al., 2010), and 25–50% in Central and South America (Hammond et al., 1996). In countries like India, all kind of banana waste is considered an important urban waste because the fruit is used in all religious functions, festivals and in temples (Chanakya and Sreesha, 2011). According to Graefe et al. (2011), around 20–40% of the bananas produced do not meet export standards or even the quality demands of spot markets. In Brazil, particularly in the southern regions, it is estimated that for every 100 kg of harvested fruit, 46 kg are not used (EMBRAPA, 2006). Further, Souza et al. (2010) indicate that for every ton of bananas produced approximately 3 tons of pseudostem, 160 kg of stems, 480 kg of leaves and 440 kg of skins are generated. Fernandes et al. (2013) found that less than 10% of available biomass as waste (440 million tons) is designated to some application. Thus, an established commercial use for such residues, as well as generating extra remuneration for regional farmers, would help to reduce environmental pollution. Alternative uses for these discards have to be explored, and in this regard processing to produce ethanol is seen to have potential from both an environmental as well as an economic point of view.

Many countries are investing in the development and use of biofuels as a way of reducing environmental impacts and ethanol

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is one of the fuels that can be produced from various raw materials (España-Gamboa et al., 2011). The use of agricultural or agro-industrial waste is an interesting option in this context. Biofuel has been produced on a large scale in Brazil for three decades using sugarcane as feedstock (Soccol et al., 2010), however there are many criticisms of the practice and an ongoing debate about the ethical issue of using food (or land available for the cultivation of food) as an energy source (Sarkar et al., 2012; Swana et al., 2011). Lignocellulosic material does not play an intrinsic role in the food chain and this is a fundamental aspect that makes it an attractive alternative for ethanol production. Besides, the cost and availability of the feedstock are crucial and can contribute 65–70% to the total ethanol production costs (Kazi et al., 2010). In this sense, the substitution of biomass wastes for raw materials such as cane sugar, starch and corn for ethanol production is an alternative that has shown promising results (Dermibas, 2011; Mabee et al., 2011). Examples of this residual biomass include bagasse sugar cane, corn straw and fiber, wheat and rice straw, eucalyptus wood and crop wastes from commercial cultivation of fruits such as bananas, grapes and apples (Rivas-Cantu et al., 2013).

Technologies for the conversion of biomass to ethanol are also under various stages of development. The use of these lignocellulosic residues requires some separation of cellulose and hemicellulose from lignin, followed by hydrolysis of sugars, and this bioconversion has been extensively studied using the different types of wastes. The potential yield of ethanol from lignocellulosics varies significantly between feedstocks, so many applications in alcoholic fermentation are reported in the literature with different wastes. Specifically in the case of ethanol from bananas, the few studies that have been published involve the use of the fruit, leaves and other waste such as the pseudostem. Tewari et al. (1986) reported the suitability of banana peel for alcohol fermentation. Hammond et al. (1996) presented ethanol yield (on a dry weight basis) from ripe bananas as higher than from most other agricultural commodities. Velásquez-Arredondo et al. (2010) investigated the acid hydrolysis of banana pulp and fruit and the enzymatic hydrolysis of flower stalk and banana skin, and the results obtained demonstrated a positive energy balance for the four production routes evaluated. The study by Graefe et al. (2011) presents results of a case study in Costa Rica and Ecuador which found that considerable amounts of ethanol could be produced from banana bunches that do not meet quality standards, as well as from which are partly left to rot in the fields. Oberoi et al. (2011) also demonstrated that banana peel could serve as an ideal substrate for the production of ethanol through simultaneous saccharification and fermentation. Hossain et al. (2011) evaluated bioethanol from rotten banana and concluded that this can be used in motor vehicle engines, producing low emissions, and thus it can be used as an environmental recycling process for waste management. Arumugam and Manikandan (2011) explore the potential application of pulp and banana peel wastes in bioethanol production using dilute acid pretreatment followed by enzymatic hydrolysis. Gonçalves Filho et al. (2013) evaluate the same techniques with banana tree pseudostem.

Although the lignocellulosic material shows positive results, it still requires more research to be exploited on an industrial scale. Great efforts are being undertaken to improve ethanol productivity and reduce the overall production costs. According to Gaykawad et al. (2013), one of the ways to achieve these goals is to modify the configuration of the process and perform process integration. Traditionally, the recovery of ethanol by distillation is a challenge because of the high costs and energy expenditure required (Vane, 2008). Toward this end, membrane separation processes such as pervaporation have been used. The great interest in these processes is mainly because of features such as cost-effectiveness, high energy efficiency and environmental friendliness. Membrane based separation technologies normally fulfill the criteria for sustainability and energy efficiency (Korelskiy et al., 2013). In addition to reducing the inhibition of ethanol in the production stage due to the possibility of its simultaneous use with fermentation (Lewandowska and Kujawski, 2007), this procedure could replace a concentration step that is required for recovery because of the presence of alcohol in small quantities in the broth (Nomura et al., 2002). As shown by Chovau et al. (2011), the composition of the fermentation broth influences the separation, and the use of different substrates leads to the need to reevaluate the process, even if it is already well established. Also, in multicomponent systems, the diffusivity of one component is influenced by the presence of others. The use of lignocellulosic biomass will not only affect feedstock pretreatment and fermentation process of the ethanol production but also the downstream processing (Gaykawad et al., 2013).

In pervaporation, a liquid mixture is fed through a membrane. The mixture components permeate selectively through the membrane and vaporize on the other side of the membrane where low pressure is maintained. By this means, there is a selective removal of organic compounds from dilute aqueous solutions. There are several studies regarding ethanol pervaporation and they relate mainly to the use of different membranes. Specifically the pervaporation of ethanol from lignocellulosic residues is reported by Gaykawad et al. (2013) with barley straw and willow wood using commercial polydimethylsiloxane (PDMS) membranes. Zhang et al. (2012) studied the membrane fouling in pervaporation of ethanol from food waste after a flocculation–filtration pretreatment. Aroujalian and Raisi (2009) study the effects of various operating parameters such as feed temperature, permeate side pressure, and Reynolds number (volumetric flow rate) on the total flux, and ethanol selectivity of a porous membrane-based pervaporation process with 2% aqueous ethanol solutions, simulating an ethanol content from lignocellulosic residues. O'Brien et al. (2004) related an efficient system of coupled fermentation and pervaporation for ethanol from corn fiber hydrolisates.

Studies of pervaporation in ethanol production hitherto have not used banana waste as a substrate for ethanol production. Thus the aim of this research is to evaluate if pervaporation can be used in the production of ethanol from banana and to investigate the effects of operating variables and of lignocellulosic biomass fermentation by-products on membrane performance for the recovery of ethanol by using pervaporation.

2. Materials and methods

To investigate the membrane behavior, first model solutions of ethanol/water were separated in pervaporation experiments to characterize ethanol transfer across the hollow polydimethylsiloxane (PDMS) membrane and these results provided the reference for the broth experiments.

In the first case, feed conditions (flow rate, temperature, ethanol composition) and permeate pressure were modified. Also, the time necessary to reach steady state was determined. Then, tests were performed with the fermentation broth produced using banana fruit waste as a substrate varying the ethanol feed mass fraction and feed flow rate. The presence of some byproducts was also studied.

2.1. Membrane

The pervaporation unit used consisted of a removable permeation module made of polyvinyl chloride (PVC) of 0.2 m internal diameter containing 50 dense hollow polydimethylsiloxane (PDMS) membranes (d_i = 0.6 mm and d_e = 1 mm), 0.25 m in length,