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Production of colorless liquid sugar by ultrafiltration coupled with ion exchange

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A B S T R A C T

Liquid sugar is an alternative product to crystal sugar, which is currently being considered by many sugar companies. However, production of colorless liquid sugar is still a big challenge. This work aimed to study the performance of ultrafiltration membrane and ion exchange (IE) both as single and integrated processes for decoloring cane sugar solution. The experiments were performed by using 10, 20, 50, and 100 kDa commercial UF membranes. Two commercial resins were used in ion exchange experiments. The results of decoloring sugar solution using UF membranes showed that the 20 kDa UF membrane made of polysulfone displays the best performance in term of flux and color removal. Integrating ion exchange process into UF membrane improves the color reduction resulting colorless liquid sugar. The UF–IE configuration shows a better performance than both the IE–UF and UF/IE alone configurations. These results provide important information about technologies that should be used for liquid sugar production.

1. Introduction

Sugar is one of the commodities that have a strategic role, because it is one of the basic needs of domestic and industries for food, beverage and pharmaceutical. Due to energy saving, liquid sugar is currently being considered to replace partly crystal sugar products. It is known that in most of the food or beverage industries crystal sugar is dissolved in water before use. The energy for dissolution can be avoided if liquid sugar is used. Further energy used for crystallization in crystal sugar industry can also be avoided if liquid sugar is produced. It was reported that crystallization is one of the most energy-intensives stages in crystal sugar industries (Chen and Chou, 1993; Maravic et al., 2015; Wang, 2009). However, production of liquid sugar needs technologies that can produce colorless sugar solution with high content of sugar and a low concentration of non-sugar. It is not easy to fulfil those requirements because (i) sugar cane juice contains various components, of which only sugar is desirable, (ii) the juice extracted from sugarcane are naturally yellow–brown, (iii) many macromolecules, small molecules and minerals present in sugar cane juice that should be removed, (iv) the possibility of color increasing during processing as a result of browning reactions, and (v) the increase in viscosity of sugar solution as increase in sugar concentration causing a problems in purification (Balakrishnan et al., 2000a,b; Chen and Chou, 1993; Hinkova et al., 2002; Jegatheesan et al., 2009; Saha et al., 2006).

Many technologies have been developed to increase the performance of crystal sugar industry or cane sugar refinery, i.e., either to increase purity of sugar or to decrease production cost. One promising alternative is the use of ultrafiltration (UF)

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membrane for sugar cane juice clarification either stand alone or combined with the coagulation process (Balakrishnan et al., 2001; Bhattacharya et al., 2001; Donovan et al., 2002; Fechter et al., 2004; Ghosh et al., 2000; Ghosh and Balakrishnan, 2003). In general, UF membranes offer (i) increasing the transmission of sucrose, (ii) improving the quality of sugar, (iii) increasing the yield of conventional process, and (iv) reducing the chemical and energy used. However, most of previous publications of application UF membranes are dedicated to production of crystal sugar, where permeate of ultrafiltration membrane will further be processed by crystallization (e.g., Balakrishnan et al., 2000a,b; Chen and Chou, 1993; Jacob and Jaffrin, 2000; Mak, 1991). In this context, the color of sugar solution resulting from UF permeate is not requested to be at a low level. Besides its function to form sugar crystal, crystallization process can also play as a decolorization process via excluding colorants from sugar crystals during crystal growth as well as crystal washing after being separated from the liquor. By contrast, no crystallization process is used in production of liquid sugar.

To produce high quality of liquid sugar, we need technologies that can eliminate soluble non-sugar macromolecular and colorants. Removal of colorants from liquid sugar is very important because color is the most significant quality determinant. Colorants in sugar cane juice can originate from native of sugarcane plant such as flavonoids and melanins and those developed during cane juice processing such as melanoidins and caramels (Flood and Flood, 2006; Hamachi et al., 2003). This colorization increases during processing as a result of enzymatic reactions and heat induced procedures involved. Sugarcane juice contains 3–5% of soluble solids in the form of colorants, color precursors, etc. and an additional 0.85–1.45% of soluble solids in the form of organic non-sugars such as protein, polysaccharides and waxes (Chen and Chou, 1999). Several techniques can be used for removing color from the sugar solution including ion exchange (IE), activated carbon and UF. Among them, UF and ion exchange seem to be of highest relevance from practical point of view.

UF membrane has been proposed as an attractive technology for color removal in production of crystal sugar and others (Decloux et al., 2000; Hamachi et al., 2003; Jacob and Jaffrin, 2000; Mak, 1991). However, this technology has low efficiency for removing color originating from very small macromolecules or minerals. The use of nanofiltration membrane may be able to remove such small colorants but it can also reduce sugar content. Ion exchange (IE) has been applied in many food industries (Achaerandio et al., 2002; Lyndon, 1996). In principle, this technology can be used for softening, demineralization and decolorization. Application of ion exchange for sugar cane juice decolorization was reported in previous publications (Bento, 1990; Lin and Chen, 1991). However, the use of IE technology is limited by its high operating cost due to resin regeneration. In addition, high amount of wastewater will be resulted from regeneration process.

In summary, UF and IE have been proposed for decoloring cane sugar solution or sugarcane juice. However, most of previous studies on decolorization of sugar solution were performed using single process, i.e. either UF or IE alone. The objective of the current study was to examine the performance of ultrafiltration membranes and ion exchange for the decolorization of sugar solution. Measurements of the permeate flux and other key parameters of the separation were also performed to determine the viability of the UF membrane process. The important investigation was the performance of combination of both technologies. The process configuration of UF and IE for colorant removal to obtain colorless sugar solution was investigated.

2. Materials and methods

2.1. *Materials*

For identification of suitable membranes, commercial polysulfone (PS) and polyethersulfone (PES) UF membranes with different pore sizes (represented by MWCO, molecular weight cut off) and one UF membrane made from fluoro polymer were used in this study. The membranes tested were GR81PP (10 kDa, polyethersulfone, called PES-10), GR61PP (20 kDa, polysulfone, called PS-20), GR51PP (50 kDa, polysulfone, called PS-50), GR40PP (100 kDa, polysulfone, called PS-100), and FS61PP (20 kDa, fluoro polymer, called FP-20). All membranes were supplied by Alfa Laval, Denmark. The membranes were initially washed by soaking overnight in water to remove impurities or additives left from the manufacturing process before use. Fresh membranes were used in all experiments. Brown sugar crystal was purchased from the local sugar company in Indonesia. Sodium hydroxide and hydrochloric acid were purchased from Merck. Lewatit adsorber resins, i.e., S 6368 (R1) and OC 1074 (R2), were used for ion exchange process. S 6368 (R1) is strongly basic macroporous anion exchange resin (type I) with beads of uniform size (monodisperse) based on polystyrene. OC 1074 (R2) is a strongly basic macroporous type I anion exchange resin based on polyacrylamide. It is bead-shaped and has a special bead size distribution. Demineralized water from home-made RO-ion exchange system was used for all experiments.

2.2. *Methods*

2.2.1. *Ultrafiltration experiments*

Ultrafiltration experiments were performed by crossflow filtration using a self-home-made laboratory scale similar with our previous publication (Susanto and Widiasa, 2009). The set-up consisted of a feed tank, a pump, a pressure indicator connected to feed side and a flat-sheet membrane cell made of stainless steel. The cell has a diameter of 10 cm with a 4 cm diameter membrane holder. A simplified diagram of the set-up is given in Fig. 1. In each experiment, a new circular membrane disk with the effective area of 0.00125 m^2 was used and was firstly compacted by filtering pure water for at least 0.5 h at a pressure of 3 bars. In order to maintain constant feed concentration, the volume of feed was much larger than the volume taken as sample for the analysis. In addition, the retentate and permeate were returned back to the feed tank. During UF experiments, the flux profile over time was gravimetrically monitored. All experiments were conducted at room temperature ($28 \pm 2\,^{\circ}C$) and at a constant transmembrane pressure (300 kPa for PES-10 and 100 kPa for PS-20, PS-50, PS-100 and FS-20). The transmembrane pressure drop (the difference between feed pressure and retentate pressure) was less than 0.1 bar. The sugar content, color, and absorbance of feed and permeate were analyzed. The apparent color rejection was calculated using Eq. (1).

$$R = 1 - \frac{C_d}{C_u} \qquad (1)$$