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Influence of pluronic addition on polyethersulfone membrane for xylitol recovery from biomass fermentation solution

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ABSTRACT

Xylitol is a by-product that is obtained from the production of bioethanol. A lignocellulosic biomass contains an abundance of xylose that acts as a precursor in the production of xylitol. The xylitol produced from biomass sources through biological route is a cleaner production than the common chemical route, which involves least sustainable processes. However this xylitol may contain other impurities and sugars that are difficult to separate due to their close molecular weights. A highly concentrated xylitol can potentially be obtained through the use of a pressure filtration membrane as a potential cleaner production technology due to the unique properties of the membrane including low energy requirement, high separation performance, and high selectivity between xylitol and sugars. In this work, a specially blended polymeric membrane was synthesized, characterized and tested in the recovery of xylitol from a synthetic biomass fermentation solution. Pluronic f127 at different ratios of 1, 3, and 5% was blended with Polyethersulfone (PES) to modify the PES membrane. The effect of the Pluronic ratio on the selectivity of the PES membrane in the separation of xylitol from sugars and also the fouling mitigation effect under the presence of Pluronic in the membrane were investigated. The results showed an improvement in the hydrophilicity of the membrane, where the contact angle of the pure PES membrane dropped from 80° to 65° following the addition of Pluronic at different ratios. The water flux also increased with an increase in the Pluronic ratio. The rejection of xylitol was found to decrease in the presence of Pluronic, and a reasonable xylitol selectivity was obtained. Surprisingly, the selectivity of the membrane towards xylitol was further enhanced by the presence of ethanol in the synthetic fermentation solution. Therefore, the PES blended Pluronic membrane was shown to have a great potential for the separation of xylitol from sugars.

1. Introduction

Lignocellulosic materials are widespread, cheap, and excessively available substances, and can be considered as an economic source of polysaccharides (Anwar et al., 2014). Lignocellulosic materials are classified into (i) plant residuals that are derived mainly from various agricultural and farming activities, (ii) energy crops that are developed for biofuel or power, and (iii) wood deposits from woodland logging destinations and administrative operations (Abdul et al., 2016). Regrettably, burning the lignocellulosic materials is still the most popular approach for their disposal. These lignocellulosic materials can possibly be converted into various value-added products including xylitol. Forests, farm waste, and agro-industrial garbage are responsible for the production of valuable products such as sugars and biofuels (Pereira et al., 2015). Their residues are available as natural matter which are comprised of, 11–30% lignin 19–34% hemicellulose, and 34–50% cellulose, as well as reduced amounts of inorganic matter, protein, and pectin (Kumar et al., 2009). Lignocellulose was found to be rich in sugars like arabinose, galactose, and xylose with approximately 99,780 tons of renewable sugars could be produced annually from ten neighbouring palm oil mills in Malaysia (Zahari et al., 2015). Xylitol is a natural sweetener that can be extracted from any woody fibrous

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plant material. It is extracted commercially from renewable resources such as palm fronds, which are environmentally sustainable sources.

Xylitol is evolving in foods, cosmetics, and medicines as it can be considered a very attractive source of sugar. It is effectively valuable for dental care as it diminishes cavities if used constantly and it assists in remineralisation, and is one of the most broadly appealing sugar liquor in the world, being positioned at the highest point for sweeteners with low calories, (Misra et al., 2011). Xylitol could be found in nature as small amounts in fruits like strawberries and kiwifruits. The direct extraction of xylitol from fruits is relatively considerably difficult and non-beneficial (Murthy et al., 2005). Xylitol could apparently be produced from xylose via (i) biotechnologically by using fungi, bacteria, or yeast or (ii) chemically using acid hydrolysis (Martínez et al., 2015). The biotechnological route for xylitol production is reliable, environmentally acceptable, and gives a better yield and profitability (Pappu and Gummadi, 2016). This biologically produced xylitol needs to be purified as it consists of other by-products, mainly sugars.

Membrane technology has attracted researchers' concern as a cleaner production technology for the xylitol and sugars recovery from biomass industry, which can be illustrated as in Fig. 1. Over the last decades, lignocellulosic materials and their by-products

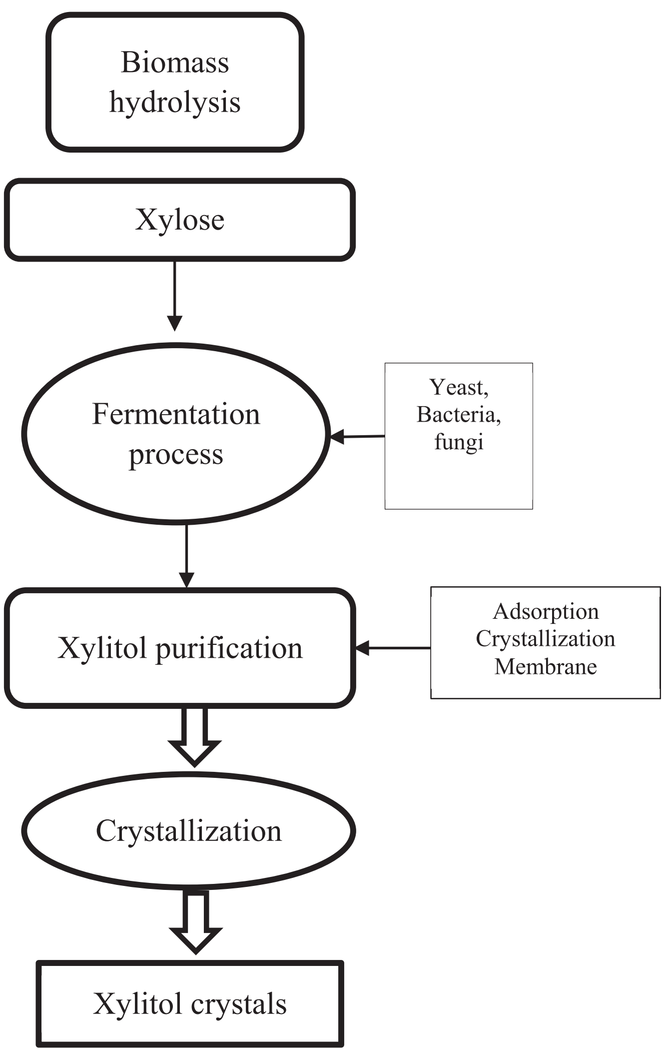

Fig. 1. Simplified flow chart of cleaner production of xylitol produced via bioconversion processes.

especially xylitol and sugars have received much attention for their nutritional properties. Compared to other separation technologies, the low energy demand, high separation efficiency, minimizing the number of processing steps and high quality of the final product are the main attractions of membrane separation and showing great sustainability in bioprocessing and bio-recovery industries. A common method for the purification of xylitol from sugars involves the breakdown of the sugars at different separation performance rates through membrane filtration (82%) (Affleck, 2000), crystallization (75%) (Canilha et al., 2008), or adsorption (65%) (Marton et al., 2006). The higher the percentage, the better the separation and purification of xylitol. Based on that performance percentage, it is expected that membrane technologies would give the best range of xylitol separation, without looking at the near sugars molecular weight (MW) (arabinose, xylose, and xylitol) that are present between 152.25 and 150.15 g/mol. As the molecular weight cut-off (MWCO) of the membrane used for the separation is between 150 and 1000 Da, the MW of these sugars are in the range of nanofiltration (NF) (Murthy et al., 2005). Conventional separation for a membrane relies mainly upon: (i) the variance in the solutes present in the solution in terms of the size, shape, structure, and charge of the solutes, or (ii) the charge between the solution and the membrane itself. It is believed that the separation of xylitol from arabinose and xylose would be quite challenging due to their close molecular weights and the neutrality of those organic substances. Eleven various membranes, ranging from ultrafiltration (UF), NF, to reverse osmosis (RO), have been used by Affleck (2000) in order to purify xylitol from a fermentation broth that contains arabinose, xylose, and xylitol. The UF membrane exhibited the best separation performance compared to the other membranes and there was no observed significant selectivity between xylitol and other sugars. The polymers like Polyamide (PA) and PES were frequently used as a main polymer for the membrane synthesis (Cui et al., 2010). PES has many merits, for instance, it is commonly used in NF and UF, as well as microfiltration (MF) processes (Ulbricht, 2006), and it has high thermal and mechanical properties and possesses vast pH tolerance (Lin et al., 2016). The main PES disadvantage is the lack of hydrophilicity, in which fouling could occur during the process of filtration. The membrane fouling remains the single most important challenge for the application of the membrane processes. A good understanding of fouling mechanisms and fouling control strategies as well as the development of a suitable membrane system will help to minimize fouling issues.

It is necessary to modify the synthesis of the membrane by adding a copolymer and/or nanoparticles to the main polymer to rise up the membrane hydrophilicity so as to decrease fouling. Several researches were carried on to study the fouling effects during membrane filtration. Desirable membranes needed for the industry should have good features such as stability, antifouling properties and compatible with the environment (Khalilpour et al., 2015). Fouling issue is extremely affected the filtration process and limiting the potential of the membranes, it causes higher operating cost and more energy demand (Shi et al., 2014). Fouling is present as a cake formation either in the membrane pores and on the membrane surface (irreversible fouling, R_{ir}), or just on the surface of the membrane (reversible fouling, R_r) due to the molecules adsorption in the solute (Heidi Lynn et al., 2012). The reversible fouling occurs because the membrane pores are smaller than the solution particles and can be cleaned by water flushing or backwashing. In the irreversible fouling, the particles of the solution are the same size or smaller than the membrane pores, and it is difficult to remove them through the use of any classic techniques, excluding by chemical cleaning (Richards et al., 2012). The minimizing of the membrane fouling can be either by: (i) incorporating nanoparticles into the membrane (Yang and Mi, 2013) or (ii)