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Beer dealcoholization using non-porous membrane distillation

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ABSTRACT

In this present work, performance of non-porous membrane distillation method is investigated during beer dealcoholization process. A thin-film composite polyamide membrane is used as membrane module while a commercial beer product with 5%-volume ethanol is used as feed. The results indicate that non-porous membrane distillation can be used to dealcoholize beer without losing the other nutrients and flavoring components such as maltose and glycerol. The increase of feed pressure and vacuum pressure can improve membrane flux due to higher permeability. However, membrane selectivity is decreased with the increase of vacuum pressure. The membrane flux and ethanol concentration in permeate are 0.15–0.76 L/m^2 h and 3.66–4.64%-vol., respectively. Meanwhile, there are no specific sequences on the maltose concentration in the effect of operating conditions. The slight loss of maltose in the dealcoholized beer can be attributed to adsorption phenomena in membrane surface thus membrane flushing may be conducted to recover it. The glycerol behavior in dealcoholization process is similar to maltose. Some glycerol compounds are found in the permeate stream but all of them are less than 0.005%-vol. At 3000 mbar feed pressure and 580 mbar vacuum pressure, the flux of membrane is 0.69 L/m^2 h with 3.70%-vol. and 4.60%-vol. of ethanol concentration in dealcoholized beer and permeates side respectively, no maltose and only 0.001%-vol. glycerol in permeate side. A long run operation for beer dealcoholization using these operating conditions can reduce the alcohol content from 5%-vol. to 2.45%-vol. in 6 h.

1. Introduction

The market of non-alcoholic beer keeps increasing in the last few years because there are regulations concerning health and religion issues (Catarino and Mendes, 2011a,b). Non-alcoholic beer is a beer with very low (<0.1%) or no alcohol content (Perpète and Collin, 2000). In most of the EU countries beers with low alcohol content are divided into alcohol free beers (AFB) containing ≤0.5% alcohol by volume (ABV), and to low-alcoholic beers (LAB) with no more than 1.2% ABV (Montanari et al., 2009). AFB and LAB have been produced and distributed widely in America and some European countries. Both AFB and LAB are valued with higher price than normal beers.

Non-alcoholic beers can be produced by interrupting the fermentation process of beers (Kunze, 1999). Another alternative process for low-alcoholic beverages is ethanol removal from a completely fermented beverage. The alcoholic contents removed from the beer can be used for various uses and not considered as waste. One of the usage for the alcoholic contents is for bioethanol fuel. However, most of these methods produce beers which lack nutrient and flavoring content compared to normal beers.

In order to dealcoholize alcoholic beverages without reducing the aroma and flavor contents, researchers consider the usage of membrane methods which are permeable only for alcohol such as osmotic membrane distillation (Varavuth

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et al., 2009; Gostoli, 1999; Liguori et al., 2013a,b), dialysis membrane (Branyik et al., 2012), pervaporation membrane (Tan et al., 2005; Takacs et al., 2007; Catarino and Mendes, 2011a,b; del Olmo et al., 2014), nanofiltration membrane (Labanda et al., 2009; Catarino and Mendes, 2011a,b), reverse osmosis (Branyik et al., 2012; Catarino et al., 2006; Gil et al., 2013; Pilipovik and Riverol, 2005), and membrane contactor (Liguori et al., 2010; Diban et al., 2008, 2013).

Membrane distillation method is a separation process that is energy efficient compared to other methods such as reverse osmosis or distillation. Membrane distillation has various advantages such as: 100% theoretic rejection of ions, colloids, biological cells, and non-volatile components; low operation temperature, low operation pressure, less chemical interactions between membrane and process fluids, less vapor gap than distillation, and simple membrane mechanical characteristics. Even though membrane distillation has many advantages, this system also has many limitations, such as the feed solution must be dilute enough to avoid membrane wetting (Lawson and Lloyd, 1997).

Membrane distillation is one of thermally based membrane processes in which the membrane is not directly involved in separation and acts as barrier between two phases. Selectivity is determined by the vapor–liquid equilibrium thus the component with the highest partial pressure has the highest permeation rate (Mulder, 1996). For example, in the case of an ethanol/water mixture where the membrane is not wetted, both components are transported through the membrane. However, since the ethanol has higher vapor pressure, the permeation rate of ethanol is always relatively higher.

The membrane used in this study is a non-porous membrane thus has similar mechanism with pervaporation. The permeate is removed as a vapor due to low vapor pressure existing on the permeate side by applying a vacuum pump. Since the membrane has dense structure, membrane wetting is not a drawback of the process. In addition the dense structure provides another advantages for beer dealcoholization which avoid the permeation of other components in the beer.

In this study, vacuum membrane distillation method with non-porous membrane is investigated during dealcoholization of beer. The vacuum condition is introduced to create a driving force for the mass transfer of ethanol which will shift the vapor–liquid equilibrium of ethanol where the evaporation of ethanol happen followed by ethanol diffusion through the membrane. Non-porous membrane can avoid the loss of important components from beer because of diffusion through the membrane.

2. Materials and methods

2.1. Materials

The beer used in this research is Anker Bir from PT Delta Djakarta Tbk. The beer main compositions are described in Table 1. There are some peaks detected in the HPLC analysis results which can be seen in Fig. 1. However the size area of the peak is too small to be considered major component in beer. Therefore, it was analyzed only two nutritious content of the beer, maltose and glycerol. The other trace components are not included in the table because it is undetected in the HPLC analysis, thus they can be ignored. A commercial spiral wound non-porous membrane, TW30-1812-75 from DOW Filmtec (Dow Chemical Company) made from polyamide thin-film composite with 0.37 m^2 surface area is used. The maximum operation temperature and pressure for this membrane is 45 °C and 10 bar, respectively.

Table 1 – Anker Bir main compositions.

Compounds	Concentration		Retention time (min)
	(%-vol.)	(g/L)	
Ethanol	5.00	12.06	21.965
Maltose	1.01	9.43	8.932
Glycerol	0.02	0.23	13.659
Water	93.97	936.9	19.426

2.2. Methods

The membrane distillation system is described in Fig. 2. This system is operated in batch mode operation. The beer feed (3.1 L) is contained in a feed tank which is circulated by a pumping system into the membrane module. The stream is split into permeate stream that permeates through the membrane and contains mostly alcohol and water and the retentate stream that contains dealcoholized beer with reduced alcohol contents. The retentate stream is then recirculated into the feed tank and the permeate stream is then flowed onto a chiller by the help of vacuum pumping system. The alcohol contents are condensed in the chiller system.

Before the experiment is started, it is necessary to wash the membrane distillation system with demineralized water or fresh tap water by pouring the water in the feed tank and turning on the circulation pump. The washing is done for about 20–30 min and then the membrane distillation system is dried until all of the water pours out.

The process is conducted by varying operation conditions both feed pressure in the feed side and vacuum pressure in the permeate side. In the feed side, the feed tank is at room temperature. Beer is pumped into the membrane module by varying the pressure from 2 to 3 bar (gauge). Meanwhile, in the permeate side, permeate stream is at vacuum condition by varying vacuum pressure from 490 to 660 mbar. The vapor outlet is then condensed in a chiller system (4 °C). Because water is also permeated through the membrane, the other components of beer will increase in concentration. By assuming no other beer component but ethanol permeates through the membrane, we must add some makeup water to the feed tank until the initial beer volume is reached in order to maintain the concentration of other components in dealcoholized beer.

In order to identify and analyze the concentrations of various components in both permeate and retentate stream, a high performance liquid chromatography (HPLC) method is used with HPLC Waters system and Aminex HPX-87H column. The eluent used for HPLC analytical method is sulfuric acid (H_2SO_4) with 0.6 mL/min flow rate. The operation pressure for HPLC is 988 psi, and the internal and external (heater) HPLC temperature are 40 °C and 60 °C respectively. Quantitative data were obtained by comparing the peak areas of the compounds with those of standards of known concentrations. The experimental samples (both permeate streams and retentate streams) were collected for about 10 mL on the end of each run, stored in a refrigerator with cool condition (±4 °C) and were analyzed using HPLC method.