FOOD AND BIOPRODUCTS PROCESSING 98 (2016) 44–49

Contents lists available at ScienceDirect

Food and Bioproducts Processing

journal homepage: www.elsevier.com/locate/fbp

Ohmic-assisted hydrodistillation: A novel method for ethanol distillation

Mohsen Gavahian[a,*], Asgar Farahnaky[b], Sudhir Sastry[a]

[a] Department of Food, Agricultural and Biological Engineering, The Ohio State University, 590 Woody Hayes Drive, Columbus, OH 43210, USA
[b] School of Biomedical Sciences, Graham Centre for Agricultural Innovation and ARC Transformation Training Centre for Functional Grains, Charles Sturt University, Wagga Wagga, New South Wales, Australia

ARTICLE INFO

Article history:
Received 14 August 2015
Received in revised form 24 November 2015
Accepted 29 November 2015
Available online 11 December 2015

Keywords:
Ethanol
Energy saving
Distillation
Ohmic-assisted hydrodistillation
Hydrodistillation
Ohmic heating

ABSTRACT

Distillation is one of the most time and energy consuming steps in bioethanol production and some food operations. Ohmic-assisted hydrodistillation (OAHD) is a new proposed extraction method which uses the advantages of ohmic heating and has been used for essential oil separation. In this study, an OAHD device was designed and developed for ethanol distillation using titanium electrodes. Results of the OAHD process were compared to those of traditional hydrodistillation (HD) at constant wattage of 168 W for 3 L of 10% (v/v) ethanol solution containing 0.5% (w/v) sodium chloride as the electrolyte. Results indicated that the required energy for separation of ethanol in OAHD was 33% less than HD. In addition, OAHD completed the distillation process in 75.2 ± 2.2 min while HD required 108.4 ± 5.3 min. The concentrations of ethanol in the final distilled product from both methods were similar (47.3% ± 3.2 for OAHD vs. 50.0% ± 2.6 for HD). Interestingly, in OAHD, process control is faster and distillation can be stopped in seconds and consequently, less unwanted distillate in comparison to HD (0.05% ± 0.01 and 2.28% ± 0.03 of total distilled product, respectively). The findings of this study introduce OAHD as a potentially economical and environmentally friendly method for the ethanol distillation process.

1. Introduction

As the demand for energy continues to increase globally, fossil fuel usage will likewise continue to rise. There is still a plentiful supply of fossil fuels at reasonably low cost, although this is likely to change in the future, but more critically the ever growing use of fossil fuels is unlikely to be sustainable in the longer term principally due to the attributed increase in greenhouse gas emissions from using these fuels and the environmental impacts of these emissions on global warming (Hill et al., 2006). There is therefore significant interest in identifying alternative renewable sources of fuels that are potentially carbon neutral (Hill et al., 2006; Rittmann, 2008; Demirbas, 2009). It was previously reported that ethanol and gasoline mixtures can be used as fuels for reducing environmental contamination. In addition, blending gasoline with anhydrous ethanol has been reported to improve octane index (Meirelles et al., 1992).

Ethanol is usually produced by the fermentation process although at a relatively low concentration. Its concentration in production media can vary from less than 3 to more than 12% depending on raw materials and fermentation conditions. To obtain a fuel-grade product, levels of ethanol should be increased to more than 99% (ASTM Standard D4806, 2010). Distillation is the most common separation operation for miscible liquid mixtures in the chemical industry, including facilities producing ethanol (Zacchi and Axelsson, 1989). Recovery of ethanol from the fermentation broth starts by distillation

---

* *Corresponding author*. Tel.: +1 614 292 3508.
E-mail address: mohsengavahian@yahoo.com (M. Gavahian).

http://dx.doi.org/10.1016/j.fbp.2015.11.003

of the dilute aqueous alcohol to reach a concentration of about 96% ethanol by repeating distillation several times and followed by a hydrophilic molecular-sieve-based drying system. The energy used for distillation can reach up to 40% of the total energy demand in bioethanol production (Huang et al., 2008). Thus, using the traditional distillation method (i.e., hydrodistillation, HD) to concentrate ethanol solutions has disadvantages of being time and energy intensive, therefore alternative methods have received much recent research interest.

Ohmic heating is defined as a process wherein an alternating electrical current is passed through materials and can be used to generate heat within the product (Knirsch et al., 2010). The heating occurs in the form of internal energy transformation (from electric to thermal which is due to Joule effect) within the material (Sastry and Barach, 2000). Ohmic processing enables materials to be heated at extremely rapid rates from a few seconds to a few minutes (Sastry, 2005). This alternative heating method addresses some shortcomings of traditional heating systems by removing hot surfaces from the heating of the fluids (Sakr and Liu, 2014). Ohmic heating only works in electrically conductive fluid systems due to the necessity of ionic mobility. Therefore, materials with low electrical conductivity (e.g. ethanol–water mixtures or fermented alcoholic mixtures) may require the addition of extra electrolytes to improve their conductivity (Goullieux and Pain, 2005). Consequently, salted water is used as the liquid phase for ohmic treatments (Goullieux and Pain, 2005). Electrical conductivity is the main parameter in heating rate in ohmic heating treatments. The electrical conductivity of materials changes by temperature and the current density would vary accordingly if a constant voltage applied (Goullieux and Pain, 2005; Gavahian et al., 2012). Ohmic heating can be considered as an energy saving process in comparison to conventional heating (Goullieux and Pain, 2005; Gavahian et al., 2012). Environmental impact can be reduced by reducing electrical energy consumption provided that this energy generated from fossil fuels combustion. To obtain one kWh electricity from coal or fuel, about 800 g of CO_2 will be emitted to the atmosphere during combustion of fossil fuels (Ferhat et al., 2006). Ohmic heating as an alternative extraction technique of medicinal plants was reported by Sensoy and Sastry (2001). This heating system in combination with a Clevenger type apparatus was recently utilized for the extraction of essential oils from some medicinal plants and named “ohmic assisted hydrodistillation” (OAHD). Previous studies have shown that this new method consumes less energy and has shorter extraction times in comparison to traditional HD systems (Gavahian et al., 2011, 2012, 2013). Therefore, ohmic heating (OAHD) is thought to be advantageous in the ethanol distillation process.

The main objectives of this study were to evaluate the efficacy of using OAHD as an alternative method to traditional HD for ethanol separation and concentration, and compare the time and energy demands of these two methods.

2. Materials and methods

2.1. *Solutions preparation*

Three liters of 10% (v/v) of ethanol (300 mL ethanol 200 proof DeconLabs, USA and 2700 mL distilled water) containing 0.5% (15 g) NaCl (as the electrolyte) were prepared. This salt concentration was selected to imitate the conductance of an available sample of fermented corn broth (electrical conductance of 0.4 S/m). These samples were placed in the heating vessel for the distillation process (using either traditional HD or OAHD). Prior to the distillation process, the temperatures of all samples were adjusted to 31 ± 1 °C by preheating the heating chamber.

2.2. *OAHD*

OAHD was performed using an ohmic distillation device equipped with stainless electrodes (coated by titanium), designed and developed in the Department of Food, Agricultural and Biological Engineering, The Ohio State University (Fig. 1). The electrodes were in rectangular shape and with dimension of 37 mm by 55 mm. The treatment vessel was a normal round-bottom laboratory glass flask with capacity of 5 L which was connected to a condenser (with the length of 920 mm). Processing parameters (i.e. processing time, temperature, applied voltage, current density and power consumption), were precisely monitored using a software developed and connected to the computer via a data logger similar to that described by Ramaswamy et al. (2014). Electrical conductivity is the main parameter in heating rate in ohmic heating treatments (Goullieux and Pain, 2005). As the electric conductivity of materials changes by temperature (Goullieux and Pain, 2005), the current density would vary accordingly. Therefore voltage was adjusted to keep the OAHD device running in constant wattage of 168 ± 5 W. Input voltages were controlled from the power supply of the ohmic device using a variable autotransformer (The Superior Electric Company, Bristol, CT, USA).

In the OAHD procedure, 3 L of salted water–ethanol mixture (containing 10%, v/v ethanol) were heated in the apparatus flask from an initial temperature of 31 ± 1 °C (similar to initial temperature of the material used in HD method). The heating process continued until the temperature reached 98 °C, so the amount of the ethanol in feed was reduced to a constant amount in all the experiments (according to the ethanol–water diagram) (Rieder and Thompson, 1950). As the distillation started, the amount of collected ethanol was recorded every 10 s using a digital scale (1000C-3000D Precisa, Switzerland). The distilled product was then equilibrated to 15 °C in a preset water bath (Fisher Scientific, Isotemp 1016S, USA), and the concentration of ethanol in that product was measured by an alcoholmeter (BSG HandCraft, USA).

2.3. *Hydrodistillation*

HD is the traditional method of distillation in ethanol separation (Huang et al., 2008). HD was carried out in a similar way as OAHD but by using a 5 L electromantle heater (12035-25 Hemisphere Mantle Glas-Col, USA) as the heating source (instead of ohmic heating). The device was run at a constant voltage (100 ± 5 V), current (1.6 ± 0.1) and wattage (168 ± 5 W). Otherwise, the flask and condenser used in HD were exactly the same as that used for the OAHD process. In addition, processing parameters (i.e. processing time, temperature, applied voltage, current density and power consumption) were monitored using the designed software and a data logger (Ramaswamy et al., 2014). Similar to OAHD, 3 L of 10% (v/v) ethanol (containing 0.5% NaCl) was heated in the apparatus flask from an initial temperature of 31 ± 1 °C. As with OAHD, the distillation process continued until reaching the