Journal of the Taiwan Institute of Chemical Engineers 000 (2017) 1–6

Contents lists available at ScienceDirect

Journal of the Taiwan Institute of Chemical Engineers

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

Foam fractionation for recovering whey soy protein from whey wastewater: Strengthening foam drainage using a novel internal component with superhydrophobic surface

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ARTICLE INFO

Article history:
Received 21 January 2017
Revised 24 May 2017
Accepted 26 May 2017
Available online xxx

Keywords:
Superhydrophobic coating
Foam fractionation
Foam drainage
Whey soy proteins
Wastewater treatment

ABSTRACT

Whey soy proteins (WSP) are acid soluble proteins massively existed in the whey wastewater from the process of soybean protein isolate (SPI) manufacture and they possess high nutritive values and good functional properties. For effectively recovering WSP from the whey wastewater by using foam fractionation, a novel foam column fitted with the cross internal covered by a superhydrophobic coating (SHC) was developed to strengthen foam drainage. The experimental results indicated that SHC could significantly strengthen foam drainage through decreasing the flow resistance of the interstitial liquid in the exterior channels at room temperature. The suitable length of the cross internal with SHC was 600 mm and the drainage velocity was dramatically accelerated when it was installed at 50 mm from the top of the column. Under the suitable operation conditions, enrichment ratio and recovery percentage of WSP reached 10.5 and 82.3%, respectively. This work provides a new light for strengthening foam drainage at room temperature and facilitates of the industrialization of foam fractionation.

1. Introduction

Soybean (*Glycine Max*) is an economically important crop worldwide and its seeds are rich in proteins, involving soybean protein isolate (SPI) and whey soy proteins (WSP) [1]. During the industrial production of SPI, a large volume of whey wastewater is yield at a rate of 20 t/1 t SPI and WSP mainly exist in the wastewater [2]. In recent years, WSP have attracted increasing attention owing to their favorable physicochemical properties, such as low surface hydrophobicity and good foaming capacity in a wide pH range (pH 2–10) [3]. WSP are composed of lipoxygenase, β-amylase and cytochrome c [4]. In general, the whey wastewater is directly treated by aerobic/anaerobic processes, resulting in the heavy loss of WSP [5]. Nowadays, there is a great interest in the development of cost-effective and green techniques to recover WSP from the whey wastewater.

At present, the reported techniques for recovering WSP from the whey wastewater mainly encompassed ultrafiltration and foam fractionation [6,7]. Compared with ultrafiltration, foam fractionation has advantages of simple equipment and environmental compatibility [7]. It is widely acknowledged that enrichment ratio (E) and recovery percentage (R) are two parameters to evaluate the performance of foam fractionation, and the former is more important. E is simultaneously determined by the two critical processes of foam fractionation, namely, interfacial adsorption and foam drainage [8]. Wang et al. [9] and Zhang et al. [10] showed that it was not enough for increasing E only to rely on the intensification of interfacial adsorption. Thus, strengthening foam drainage was regarded as the more effective way to improve E of the target material. Jiang et al. [11] and Li et al. [12] attempted to recover WSP with elevating temperature to 50 °C and E increased significantly. It appeared that elevating temperature significantly improved the rate of foam drainage, resulting in a low liquid holdup. However, a high temperature not only led to high energy consumption, but also increased the difficulty of an industrial process. Therefore, the greatest challenge of foam fractionation for recovering WSP is to improve E as high as possible at room temperature.

Foam drainage was mainly caused by gravity and it also could be strengthened through decreasing the flow resistance of internal reflux [13]. One of the strategies for strengthening foam drainage was to change the structure of Plateau channel. There are two kinds of channels which constitute the Plateau channel in the foam phase: one is the interior channel and the other is the exterior channel [14]. Koehler et al. [15] obtained an experimental result that liquid velocity in the exterior channel was seven times higher

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http://dx.doi.org/10.1016/j.jtice.2017.05.027
1876-1070/

than that in the interior channel. Based on their result, Lu et al. [16] designed a cross internal which was structurally simple and significantly increased the wall contact area with the foam. Their result indicated that the more exterior channels were created, the faster foam drainage rate should get. However, the drainage efficiency of the cross internal dramatically decreased with increasing the concentration of the target material in the bulk liquid phase. In order to overcome this defect, the surface of the cross internal was covered by a superhydrophobic coating (SHC) in this work. The study of Cottin-Bizonne et al. [17] suggested that the superhydrophobic surface considerably reduced the friction of the liquid past its boundary resulting in an obvious slippage. So far, there are not any references on strengthening foam drainage through modifying the surface of the column wall or the internal component.

In this work, a novel foam fractionation column with the cross internal coating SHC was developed to concentrate WSP as high as possible at room temperature. First, the effects of SHC on the liquid holdup of the static and rising foam were investigated, respectively. Subsequently, the liquid holdup of rising foam at different temperatures was determined for evaluating the degree of foam drainage by SHC at room temperature. Finally, the effects of structure parameters of the cross internal with SHC (installation location and length) and the effects of operation parameters of foam fractionation (initial pH, volumetric air flow rate, the pore diameter of the gas distributor) on the performance of foam fractionation were investigated, respectively. The objective of this work was to effectively recover WSP from the whey wastewater and to provide a new idea for the reasonable optimization design of foam fractionation column.

2. Materials and methods

2.1. Materials and reagents

The whey wastewater was provided by Yu Xin Soy Protein Industry Co. Ltd., Shandong, China. The SHC was purchased from Zixilai Co. Ltd., China and its main composition is fluoropolymer. The contact angle (CA) and the sliding angle (SA) were measured by an optical contact angle measuring device (DSA30, KRÜSS, Germany) at room temperature. A deionized water droplet with a volume of 5 μL was dropped carefully onto the surface of the measuring material. The values of CA and SA were the average of twenty measurement values on different areas of the sample surface [18]. The CA and the SA of the SHC were 168.6° and 3°, respectively. Meanwhile, the CA of the original material for making the cross internal was 88.8°. Hydrochloric acid and sodium hydroxide (obtained from Tianjin Yingdaxigui Co. Ltd., China) were used to adjust the initial pH. Ethanol 95% (Tianjin Fengchuan Chemical Reagent Factory, China), phosphoric acid 85% (Tianjin Beifang Fine Chemical Co. Ltd., China), coomassie blue G-250 (Beijing Dingguo Biotechnology Co., Ltd., China) and bovine serum albumin (BSA) (Tianjin Lianxing Biotechnology Co. Ltd., China) were used to determine the concentration of WSP. All the reagents above were analytical grade.

2.2. Experimental procedure

Fig. 1 presents the experimental setup used in this work. The column was constructed from a glass tube of 1000mm in height with an inner diameter of 44mm. In this work, an experimental column was developed by installing the cross internal with a length of 600 mm at 50 mm from its top, and the cross internal was covered by SHC. The column with the cross internal but without SHC was used as the contrasted column. The column was tightly twined by a latex tube, which was connected to a 501 ultrathermostat (Shanghai Experimental Instrument Factory Co. Ltd., China) to control temperature. A rotameter (LZB-3WB, 60–600 ml/min, Wuhuan Instruments, China) was used to control volumetric air flow rate. A PHS-25 pH meter and a 721 spectrophotometer (obtained from Shanghai Precision & Scientific Instrument Co. Ltd., China) were used to adjust the pH and determine the concentration of WSP, respectively.

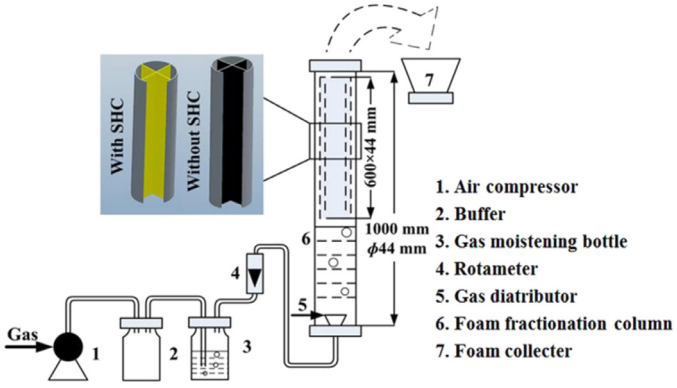

Fig. 1. Schematic diagram of the experimental setup.

2.3. Measurement of concentration of WSP

The protein concentration in the wastewater was measured by the Coomassie Brilliant Blue assay [19] at the maximum absorption wavelength of 595nm using BSA as a reference. A linear relationship between the absorbance, A_o, and protein concentration, C (g/L), was obtained where $A_o = 0.00773 + 0.0106C$ with the linear correlation coefficient $R^2 = 0.9996$.

2.4. Measurement of the total liquid holdup of the static foam

The time in which the liquid holdup became constant was 5 min and thus it was chosen as the draining time. V_F and V_L were determined by the height of the foam phase and the variation of the height in the bulk liquid phase, respectively. Thus the total liquid holdup of the static foam, ε_f, could be expressed by Eq. (1).

$$\varepsilon_f = \frac{V_L}{V_F} \tag{1}$$

where V_F is the total foam volume, L; V_L is the liquid volume contained in the foam at draining time 5 min, L.

2.5. Measurement of the liquid holdup of the foam out of the column

The liquid holdup of the foam out of the column, ε_{out}, was calculated by Eq. (2).

$$\varepsilon_{out} = \frac{V_{out}}{V_{out} + V_G} \tag{2}$$

where V_{out} is the volume of the foamate collected out of the column in 1 min, L. V_G is the volume of gas provided by the air compressor in 1 min, L.

2.6. Determination of batch foam fractionation performances

The performances used for the batch foam fractionation process were determined by enrichment ratio (E) and recovery percentage (R).

$$E = \frac{C_0V_0 - C_wV_w}{C_0V_f} \tag{4}$$

$$R = \frac{C_0V_0 - C_wV_w}{C_0V_0} \times 100\% \tag{5}$$

Please cite this article as: W. Liu et al., Foam fractionation for recovering whey soy protein from whey wastewater: Strengthening foam drainage using a novel internal component with superhydrophobic surface, Journal of the Taiwan Institute of Chemical Engineers (2017), http://dx.doi.org/10.1016/j.jtice.2017.05.027