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Enhancing the adsorption of the proteins in the soy whey wastewater using foam separation column fitted with internal baffles

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ABSTRACT

In order to promote industrialization of protein recovery from soy whey wastewater using foam separation, a novel foam separation column fitted with baffles consisting of circular disk segments placed at regular intervals in the liquid layer of the column (known as CIB in this paper) was developed to intensify the interfacial adsorption of the proteins. The column was evaluated by studying the effects of: 1. volumetric air flow rate, 2. the initial concentration of the proteins in the soy whey water, 3. the size and spacing of the disk segments on protein adsorption characteristics. The results showed that such a column could significantly intensify the adsorption of proteins. The maximum surface excess was obtained at a volumetric air flow rate of 250 mL/min, a baffle spacing of 10 mm and a disk segment chord length of 29.8 mm. At an initial concentration of the proteins of 1.8 g/L, the surface excess given by the baffled foam column was 193% higher than that given by an unbaffled column.

1. Introduction

It is known that soybean is an important crop which is abundant in proteins. At present, soybean protein isolate (SPI) is separated by alkali extraction of fine soybean powder followed by isoelectric precipitation. However, during this process, soy whey wastewater of about 20 tonne is produced per tonne of SPI, which contains proteins at a concentration of about 3 g/L. Therefore, direct discharge of the wastewater will undoubtedly result in a significant loss of proteins, let alone cause serious environmental pollution. Currently, the wastewater is treated by conventional aerobic/anaerobic processes (Zhu et al., 2008), without recovering the proteins from the wastewater. There are some literature reports on the use of membrane separation (Feng et al., 2009) for recovering proteins from the wastewater. However at industrial scale, the membrane suffers from serious fouling. It is therefore desirable to develop a simple, low-cost and pollution-free technology for protein recovery from soy whey wastewater.

Foam separation is such a technique that uses bubble interfaces to separate selected components from an aqueous solution (Burghoff, 2012; Liu et al., 2013). It is a physical process based on the hydrophobic differences of a mixture of components (Lemlich, 1968). Jiang et al. (2011) developed a two-stage foam separation technology on the basis of the effect of temperature on foam drainage for recovering the proteins from the wastewater and the results showed that a protein enrichment ratio of 8.5 can be achieved. To promote the industrialization of the foam separation technology, further enhancement in enrichment ratio is desirable.

There are the two critical steps in foam separation: interfacial adsorption and foam drainage. The former determines the adsorption capacity of the gas–liquid interface, and the latter determines the liquid holdup in the foam layer (Li et al., 2012; Narsimhan, 1991; Yan et al., 2011; Zhang et al., 2011). Therefore, interfacial adsorption and foam drainage are the two factors that dictate the efficiencies of foam separation, namely, enrichment ratio and recovery percentage (Bhattacharjee et al., 1997; Chang and Franses, 1995; Douillard and Lefebvre, 1990). Between the two, interfacial adsorption can also affect foam drainage (Germick et al., 1994; Li et al., 2011; Piazza et al., 2008), thus more attention should be paid to the enhancement of interfacial adsorption of, in this case, proteins from wastewater, using foam fractionation.

In addition to the physical properties of the feed solution and operating conditions, the column structure and configuration can also affect interfacial adsorption. However, contemporary studies on enhancing interfacial adsorption only consider the effect of the pore diameter of the gas distributer (Aksay and Mazza, 2007; Bhattacharjee et al., 1997). It is true that the optimization of the pore diameter of the gas distributer can improve the efficiencies of foam separation. However, this improvement is very limited because a smaller pore diameter typically generates smaller bubbles, which is favorable to interfacial adsorption, but the foam drainage is adversely affected. Therefore, it is pertinent to explore other ways of intensifying interfacial adsorption. One way of achieving

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this is to use internal baffles in the foam column which promotes protein adsorption by increasing the residence time of the bubbles.

In this work, a simple foam separation column fitted with internal baffles (referred to as CIB in this paper) was developed to enhance interfacial adsorption. The baffles were essentially circular disk segments, stacked at regular intervals along the column height. The effects of baffle configuration and operating variables on the adsorption characteristics were studied using the soy whey wastewater as a model system. The properties studied included bubble diameter, adsorbed mass flux, surface excess, protein enrichment ratio and recovery percentage. The design parameters of the CIB included baffle spacing and chord length of the disk segment.

2. Material and methods

2.1. Materials

The soy whey wastewater was provided by Yu Xin Soy Proteins Industry Co. Ltd., Shandong, China with a protein concentration of 2.0 g/L and pH 4.3. Hydrochloric acid and sodium hydroxide (Tianjin Yingdaxigui Co. Ltd., China) were used to adjust the initial pH of the wastewater. Ethanol 95% (Tianjin Fengchuan Chemical Reagent Factory, China), phosphoric acid 85% (Tianjin Beifang Fine Chemical Co. Ltd., China), Coomassie Brilliant 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 the proteins. All the reagents above were analytical grade.

2.2. Equipment

Fig. 1 illustrates the schematic diagram of the CIB. Fig. 2 shows the experimental setup. The column was made of a transparent plexiglass tube of 1000 mm in height and 50 mm inner diameter. A coordinate paper was attached to the column for liquid and foam level measurement.

The outlet *I* was located at 330 mm from the bottom of the column. A gas sparger made of lacunaris sintered glass with 400–450 μm pore diameter was mounted at the bottom of the column. A thermostat and a humidistat were used to control temperature and moisture of the air, respectively. A buffer bottle was used to isolate the column from the vibrations caused by the air compressor (AC0-318, Guangdong Hailea Group Co. Ltd., China).

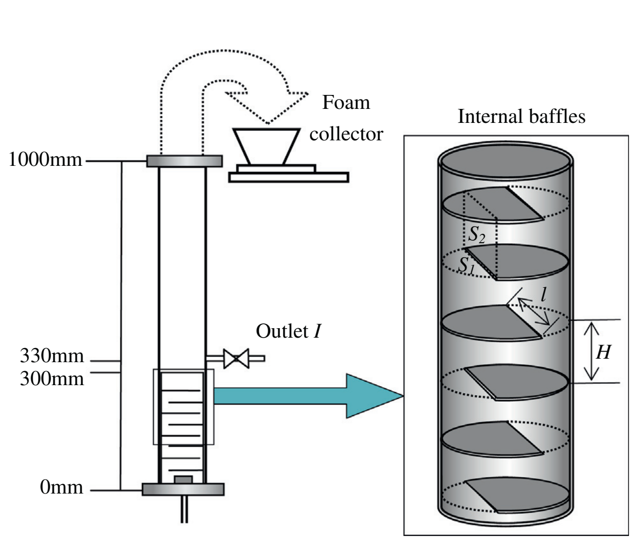

Fig. 1. The schematic diagram of the column fitted with internal baffles.

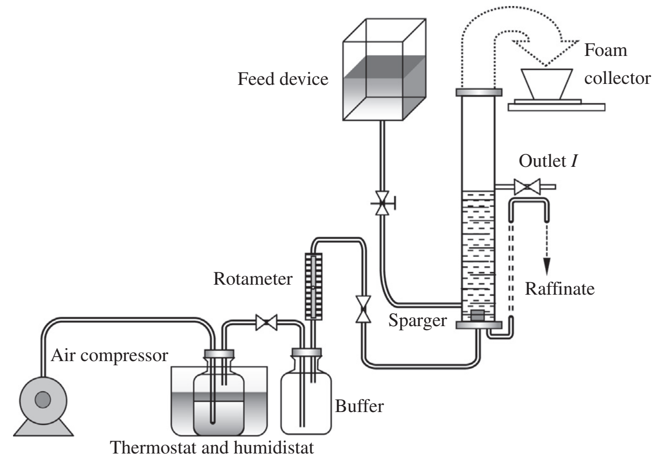

Fig. 2. The schematic diagram of the experimental setup.

A rotameter (LZB-3WB, 100–1000 mL/min, Wuhuan Instrument Factory, Tianjin, China) was used to monitor and control the volumetric air flow rate. A PHS-25 pH meter and a 721 spectrophotometer (Shanghai Precision & Scientific Instrument Co. Ltd., China) were used for measuring the pH and the protein concentrations in the wastewater, respectively.

2.3. Design of the CIB

As presented in Fig. 1, the inner diameter of the segment is 45 mm. *H* is the baffle spacing of the CIB, *l* is the chord length of the baffle. S_2 is the area of the rectangle of which the side lengths are *H* and *l*. S_1 is the area of the segment through which the gas and liquid mixture flows in the axial direction. So, S_1 and S_2 are determined by *H* and *l*. The dimensions of the CIB used in this study are shown in Table 1. Different combinations of *H* and *l* are used to give $S_1 > S_2$, $S_1 < S_2$ or $S_1 = S_2$.

2.4. Measurement of protein concentration

The protein concentration in the wastewater was measured by the Coomassie Brilliant Blue assay at the maximum absorption wavelength of 595 nm using bovine serum albumin as a reference. A linear relationship between the absorbance, A_o, and protein concentration, C (g/L), was obtained where $A_o = 0.05213 + 5.7026C$ with the linear correlation coefficient $R^2 = 0.99959$. The range of C is from 0.01 g/L to 2.0 g/L.

2.5. Determination of adsorption characteristics

The adsorption characteristics studied in the present work are surface excess, Γ, and adsorbed protein mass flux, φ_s. By assuming that the protein in the interstitial liquid of the foam has the same concentration as the bulk liquid, Γ and φ_s can be calculated using following equations.

$$C_f V_f = C_e V_f + \varphi_s \tag{1}$$

$$\varphi_s = A\Gamma \tag{2}$$

$$A = N \cdot 4\pi (D_{32}/2)^2 \tag{3}$$

$$N = 3u / \left[4\pi (D_{32}/2)^3\right] \tag{4}$$

where D_{32} is the Sauter mean bubble diameter, C_f (g/L) and C_e (g/L) are the concentrations of the proteins in the foamate from the