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Intensification of the interfacial adsorption of whey soy protein in the liquid phase using a foam separation column with the vertical sieve tray internal

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ABSTRACT

In order to improve the industrialization of whey soy proteins (WSPs) recovery from soy whey wastewater using foam separation, a novel foam separation column was developed using the vertical sieve tray (VST) as an internal in the liquid phase. The effects of the design parameters of the VST internal on the adsorption properties of WSPs were evaluated. The design parameters of the VST internal included the number of trays in the VST internal, the tray spacing and the number of vertical sieve caps in each tray. The adsorption properties of WSPs included the bubble diameter, the adsorbed mass flux and the surface excess. The results showed that the novel column significantly intensified the adsorption properties of WSPs. The maximal surface excess of WSPs was obtained at the initial WSPs concentration of 0.3 g/L, the number of trays in the VST internal of 5, the tray spacing of 60 mm and the number of vertical sieve caps in each tray of 4 and it increased 100.7% compared with the foam column without any internals in the liquid phase.

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1. Introduction

Whey soy proteins (WSPs) are a group of byproducts for producing soy protein isolate (SPI) (Li et al., 2010) and they include lactoferrin, lectin, Kunitz trypsin inhibitor, lipoxygenase, β-amylase and cytochrome *c* (Molina et al., 2001; Ray and Rousseau, 2013). WSPs exhibit several characteristics in the control of powdery mildew in crops, the formation of emulsions, the oxidation of polyunsaturated fatty acids and the combination with petroleum-based products (Wang et al., 2012; Li et al., 2010; Kumar and Zhang, 2009; Nordqvist et al., 2013). Moreover WSPs also have medicinal importance in preventing poliovirus type-1, Coxsackie virus B6, human cytomegalovirus, Herpes simplex virus type 1, human influenza virus A subtype H3N2 & subtype H1N1 and even cancer (Kobayashi et al., 2004; McCue et al., 2004; Sitohy et al., 2007). Thus, WSPs may be used in crops, pharmaceuticals, cosmetics and the production process of different industries and there will be an increasing market demand for them.

WSPs mainly exist in soy whey wastewater. A large amount of the wastewater is yielded at a rate of 20 t/1 t SPI (Wang et al., 2013). If the wastewater is discharged to the sewage treatment plants and translated into sludge by biological methods, there will be a huge economic loss of the useful materials and the excessive cost of the wastewater treatment (He et al., 2005). Therefore, the recovery and reuse of WSPs certainly become an urgent issue.

Strategies for recovering WSPs from soy whey wastewater mainly include ultrafiltration (Feng et al., 2009; Al-Muhtaseb et al., 2010) and foam separation (Mukhopadhyay et al., 2010; Jiang et al., 2011). Compared with ultrafiltration, foam separation has become a more desirable method due to its advantages (Chove et al., 2007; Linke and Berger, 2011; Burghoff, 2012; Khalesi et al., 2013) of simple equipment, low energy consumption, less investment and free pollution. The foam separation process contains two critical steps: interfacial adsorption and foam drainage. The two steps both have important effects on one of the most important performances of foam separation, namely, enrichment ratio. Furthermore, interfacial adsorption has a direct effect on the foam properties, thereby affecting foam drainage (Arabadzhieva et al., 2011). Therefore, it is necessary to pay enough attention on strengthening the study of interfacial adsorption.

Some researchers had studied the effects of physical properties (Chang and Franses, 1995; Su et al., 2010; Khalesi et al., 2013; Qi et al., 2013) and operation conditions (Maruyama et al., 2000, 2006; Nakabayashi et al., 2011; Zhang et al., 2011) on the interfacial adsorption of water-soluble proteins in the liquid phase, showing the possibility to enhance the interfacial adsorption of the separated materials. As to column structures, the effects of the distributor and the liquid phase height on interfacial adsorption

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were studied (Nguyen et al., 2006; Li et al., 2011). However, it is not enough for enhancing interfacial adsorption only to rely on the distributor and the liquid phase height. First, decreasing the pore size of a distributor is beneficial for interfacial adsorption but not beneficial for foam drainage. Second, the surface excess of the separated materials can hardly increase with increasing the liquid phase height (Li et al., 2011). Besides, for the design of foam column, it is desirable that the liquid phase height should be as low as possible. Therefore, it is important to develop a new column structure to improve interfacial adsorption in the liquid phase.

For a foam separation column without any internals in the liquid phase, the bubbles leave the distributor, move upward along the axial direction under the action of buoyancy and air-flow, arrive at the surface of the liquid phase and then enter into the foam phase. It is difficult for such bubble motion to improve the mass transfer (Lu et al., 1997) or control the residence time and the bubble size (Wang et al., 2010) in the liquid phase when the distributor and the liquid phase height are determined, respectively. A multistage bubble-cap trayed column (Rujirawanich et al., 2010, 2011, 2012) was designed to improve the mass transfer of the separated materials. However, the effects of the bubble-cap tray on interfacial adsorption were not taken into consideration. So, it is necessary to study and improve interfacial adsorption of whey soy protein by developing a more effective foam column with a new internal in the liquid phase.

A new foam separation column was developed using the vertical sieve tray (VST) as an internal in the liquid phase to study the effects of the VST internal on interfacial adsorption. The effects of design parameters on adsorption properties in the VST foam column were studied using soy whey wastewater as the model surfactant for enhancing interfacial adsorption of whey soy proteins (WSPs). The design parameters included the number of trays in the VST internal, the tray spacing and the number of vertical sieve caps in each tray. The adsorption properties included the bubble diameter, the adsorbed mass flux and the surface excess.

2. Materials and methods

2.1. Materials

Soy whey wastewater was provided by Yu Xin Soy Protein Industry Co. Ltd., Shandong, China with a protein concentration of 0.3–0.5 g/L and pH 4.5–5.5. 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) were used to measure the protein concentration.

2.2. VST foam column

The schematic diagram of the VST foam column is shown in Fig. 1. The foam column was constructed by a transparent plexiglass tube of 1000 mm in height and 48 mm in internal diameter. A sintered glass filter of 0.18 mm in average pore size was installed at the bottom of the foam column as the gas distributor. The foam column had two sidings. One was a liquid feed inlet located at 100 mm and the other was a sampling outlet located at 600 mm from the bottom of the column, respectively.

The VST internal was located in the midst of the column and the trays were connected and fixed by the sticks of which the length determined the tray spacing. A downcomer of 5 mm in diameter was located at the center of the tray to allow the liquid entrained by the rising bubbles to flow down to the lower tray. Each VST was made up of a transparent plexiglass plate of 3 mm in thickness and 48 mm in diameter and vertical sieve caps of 14 mm in external diameter and 50 mm in height. Each vertical sieve cap had 3 rows of aligned pores of 3 mm in diameter, each row had 9 pores and the center distance between the adjacent two pores was 5 mm. According to the number of the vertical sieve caps installed in each tray, 2-VST meant one VST with 2 caps in each tray and 4-VST did with 4 caps as showed in Fig. 2.

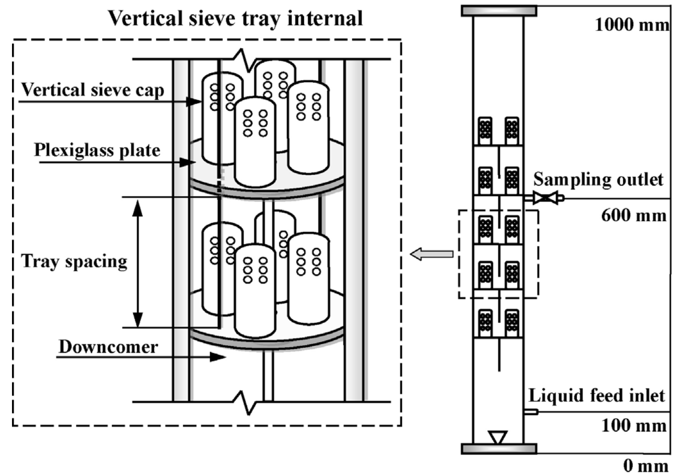

Fig. 1. Schematic diagram of the foam separation column with the vertical sieve tray (VST) internal.

2.3. Experimental procedure

The experiments were done in the semi-continuous operation process as shown in Fig. 3. The solution was charged into the column using a peristaltic pump (YW03, Changzhou Yuanwang Fluid Technology Co. Ltd., China) with the feeding rate, V_0, of 1.2×10^{-7} m^3/s. The liquid phase height, H_L, was adjusted by controlling the superficial air flux using a rotameter (ACO-318, Wuhuan Meter Factory, China). The operation temperature was 25 ± 1 °C. The foam from the top of the column was collected every 15 min and at the same time, a small amount of the liquid in the liquid phase was taken from the sampling outlet. The WSPs concentration was determined by the Coomassie Brilliant Blue assay at the maximum absorption wavelength of 595 nm (Chan et al., 2007; Liau and Lin, 2008) using a UV–vis spectrophotometer (GB7676, Shanghai Precision & Scientific Instrument Co. Ltd., China). The experiments were done until the WSPs concentrations in the consecutive three samplings were constant and then the system was considered to achieve the steady state. The bubble diameter at the steady state was measured at a height of 20–30 mm above the surface of the liquid phase using a digital photographic camera (Nikon CooLPIX P6000). A foam column without the VST interval was used as the control column. All of the experiments were at least triply repeated and the mean values were plotted in the resultant figures.

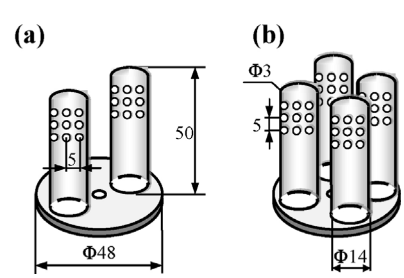

Fig. 2. Schematic diagrams of the VST internals with (a) 2 and (b) 4 vertical sieve caps in one tray.

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