Journal of the Taiwan Institute of Chemical Engineers 63 (2016) 1–5

Contents lists available at ScienceDirect

Journal of the Taiwan Institute of Chemical Engineers

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

A novel three-stage foam separation technology for recovering sodium dodecylbenzene sulfonate from its wastewater

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ARTICLE INFO

Article history:
Received 19 June 2015
Revised 15 January 2016
Accepted 28 January 2016
Available online 23 February 2016

Keywords:
Foam separation
Surfactant
Wastewater
Recovery
Intensification

ABSTRACT

Foam separation is one of the most economic and effective technologies to treat wastewaters. However when a surfactant concentration is equal to or more than its critical micelle concentration (CMC), its enrichment ratio will greatly decrease, significantly affecting its application to industries. So a novel three-stage foam separation technology was developed to intensify the process of recovering sodium dodecylbenzene sulfonate (SDBS) at a high concentration from its wastewater. The first, second and third stages of the technology aimed at increasing the SDBS enrichment ratio and recovery percentage, and decreasing the SDBS concentration in the residual solution, respectively. The synergic effects of temperature and a column of intensifying foam drainage were studied in order to enhance the enrichment ratio. By the three-stage foam separation technology, the enrichment ratio and recovery percentage reached 26.3 and 99.0%, respectively and the SDBS concentrations in the residual solution and in the foamate were 4.304×10^{-5} mol/L and 0.0981 mol/L, respectively.

1. Introduction

Surfactants have been widely used in manufactures (*e.g.* paper making, dyeing, washing) and thus they are massively lost in the industrial wastewaters, where their concentrations often are more than their critical micelle concentrations (CMCs). The national standard of GB 8978-1996 by People's Republic of China shows that for the third grade's standard, the concentration of an anionic surfactant is less than or equal to 0.020 g/L [1]. However, some methods, such as biochemical method, are not suitable to treat the surfactants at high concentrations [2–4]. Therefore, it is interesting to find an effective method to recover the surfactants at high concentrations from their wastewaters.

Foam separation is to make use of aeration to form bubbles in the liquid phase, and then the surfactants in solutions are adsorbed on the bubbles in order to concentrate and recover them. Foam separation has been industrially applied to the separation of nisin from its fermentation broth [5]. It has been shown that foam separation has the advantages of low investment, low energy consumption and environmental compatibility [6]. Therefore, it is the most suitable and effective method to industrially treat the wastewaters for recovering the surfactants.

A large number of studies have indicated that the enrichment ratio will decrease with increasing surfactant concentration [7–11]. Though a high enrichment ratio can be got by using a low surfactant concentration, the surfactant concentration in the foamate is still not high enough to meet the industrial requirements, where the foamate is the liquid obtained from the defoaming foam discharged from the top of a foam separation column. Firstly, the surfactant concentration in the foamate should be higher than that in industrial wastewaters, because the concentrations in some wastewaters are significantly higher than their CMCs. For instance, a wastewater discharged out for producing cosmetics had a concentration of linear alkylbenzene sulfonate as high as 3.148 g/L [12]. Secondly, the concentration should be more than or close to 50 g/L in order to obtain its product by spray drying. Thirdly, the concentration should be high enough to meet the demands of other purification technologies such as ion exchange to further purify the surfactant. Therefore, it is essential to improve the foam separation technology of treating the wastewaters with a high surfactant concentration.

There have been only a few studies on foam separation for concentrating surfactants at high concentrations. Tadakamalla and Marathe [13] studied the foam separation of cetylpyridinium chloride at a high concentration at room temperature. The result showed that the highest concentration in the foamate was 7.2 g/L and it was far away from the expected value for the above industrial requirements. The enrichment ratio of a surfactant at a high concentration can be increased by optimizing operation parameters. However, the effects of these parameters will decrease with increasing surfactant concentration.

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http://dx.doi.org/10.1016/j.jtice.2016.01.028
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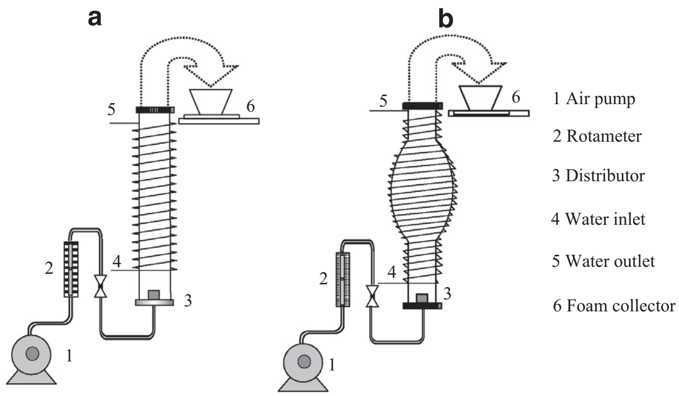

Fig. 1. Schematic diagram of the experimental apparatus (a) a conventional column, (b) a column with a vertical ellipsoid-shaped foam channel.

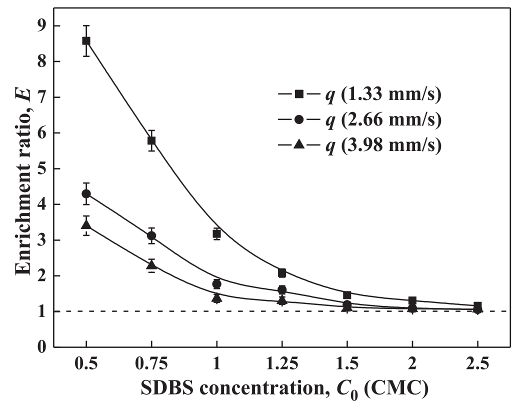

Fig. 2. Effects of SDBS concentration on the enrichment ratio. Experimental conditions: $T = 25\,°C$, $V_0 = 0.3$ L, pH 7.2 and the C_0 of SDBS ranged from 0.5 CMC to 2.5 CMC.

Sodium dodecyl sulfate (SDS) at a high concentration had been used to study the effect of temperature on the foam separation efficiency [8]. The results showed that the enrichment ratio could be enhanced by increasing temperature and the concentration in the foamate reached 22.7 g/L. However, it still could not meet the industrial requirements. Furthermore, the SDS concentration in the residual solution was as high as 2.0 g/L. A multi-stage foam separation technology could increase the enrichment ratio and recovery percentage at the same time [9,14–18]. Therefore, it is increasing to study the synergic effects of temperature and a column of intensifying foam drainage on the separation efficiency to improve the enrichment ratio of a surfactant at a high concentration.

In this work, sodium dodecylbenzene sulfonate (SDBS) was used as the model surfactant. The effects of SDBS concentration on the enrichment ratio were studied for determining its highest concentration in the feed solution, from which SDBS could be concentrated by using a conventional foam separation column. Then the wastewater of a high SDBS concentration was adopted as an actual research system. The effects of temperature on the foam separation efficiency were studied by using a conventional column. A technology of increasing the enrichment ratio of SDBS at its high concentration was developed by using a column with a vertical ellipsoid-shaped foam channel (VEC) [19,20]. Finally, a three-stage foam separation technology was developed to further decrease the concentration in the residual solution.

2. Materials and methods

2.1. Materials

An anionic surfactant, SDBS, was obtained from Sinopharm Chemical Reagent Co. Ltd., Shanghai, China with its CMC of 0.00250 mol/L at the pH of 7.2. Hydrochloric acid and sodium hydroxide were used to adjust the initial pH of the wastewater. All the above reagents were analytical grade. The SDBS wastewater was provided by a company of producing cosmetics. It had a SDBS concentration of 0.00373 mol/L, a chemical oxygen demand (COD) of 4400 mg/L, a biochemical oxygen demand (BOD) of 605 mg/L and a pH of 6.77.

2.2. Apparatus

Fig. 1 shows the schematic diagram of experimental apparatuses. The conventional column, with 40 mm in inner diameter and 1000 mm in height, was constructed by using a transparent plexiglass tube shown in Fig. 1(a). It was tightly twined by a latex tube that was connected to a 501 ultrathermostat to control the temperature of the column. A gas sparger made of lacunaris sintered glass was mounted at the bottom of the column to serve as the gas distributor and it had 425 μm in pore diameter. Fig. 1(b) is a schematic diagram of a batch foam separation operation. This column, with a vertical ellipsoid-shaped foam channel (VEC), was constructed by using a glass tube. The whole height of the column was 880 mm and the height of the VEC ranged from 320 to 660 mm. The maximum and minimum inner diameters were 98 mm and 40 mm, respectively. The other apparatuses applied in the batch foam separation were the same as those in Fig. 1(a).

2.3. Measurement of SDBS concentration

The concentration of SDBS was measured by using a 752 UV–vis spectrophotometer at the absorption wavelength of 223 nm [21]. The linear-fitting equation was $Y = 0.0308X + 0.0166$, $R^2 = 0.99994$, where Y is the absorbance, X is SDBS concentration ($(1.43–7.17) \times 10^{-5}$ mol/L) and R^2 is the linear correlation coefficient.

2.4. Determination of the separation efficiency

The foam separation efficiency in a batch operation was evaluated by enrichment ratio (E) and recovery percentage (R).

$$E = C_f/C_0 = (C_0V_0 - C_eV_e)/[(V_0 - V_e)C_0] \quad (1)$$

$$R = (C_0V_0 - C_eV_e)/(C_0V_0) \times 100\% \quad (2)$$

where V_0 and V_e are the volumes (L) of the feed solution and residual solution, respectively. C_0, C_e and C_f are the SDBS concentrations (mol/L) in the feed solution, residual solution and foamate, respectively.

3. Results and discussion

3.1. Effect of the SDBS concentration on the enrichment ratio

This section aimed at determining the highest SDBS concentration in the feed solution, from which SDBS could be concentrated by foam separation using the conventional column. The column described in Fig. 1(a) was used to study the effect of the SDBS concentration on the enrichment ratio in a batch operation. The results are shown in Fig. 2.

Fig. 2 showed that the enrichment ratio decreased from 8.57 to 4.40 at the concentration of 0.5 CMC when superficial gas velocity increased from 1.33 to 3.98 mm/s. However, the effect decreased with increasing the SDBS concentration [14,22]. The results