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Wall effect on rising foam drainage and its application to foam separation

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ABSTRACT

A novel and structurally simple foam separation column with the cross internal was developed for investigating the effect of the column wall on the drainage of rising foam, using sodium dodecyl sulfate (SDS) as a foam agent. The cross internal enhances significantly wall effect due to an increase of wall contact area in the foam phase. Furthermore, the performances of foam separation column with the cross internal were assessed using crystal violet (CV) as the model system and SDS as the collector. The insertion of the cross internal significantly decreased the liquid holdup of the foam out of the column and increased the bubble size. The results showed that an increase in wall contact area in the foam phase could enhance the drainage of rising foam due to the higher drainage velocity between the bubbles and the column wall than that between the adjacent bubbles. Under the suitable operations conditions, the enrichment ratio of CV was 16.5 by using the column with the cross internal and it was nearly four times higher than the column without the cross internal. The better performances indicated that an increase of wall contact area in the foam phase is a simple and effective method to enhance foam drainage and improve enrichment of foam separation.

1. Introduction

Foam separation, an adsorptive bubble separation technique, has been used for separating or concentrating surface-active materials [1]. It is regarded as a low-cost and pollution-free separation technique. This technique has wide applications in purification of biosurfacant [2–4], floatation of mineral [5,6] and wastewater treatment [7–9].

Enrichment ratio and recovery percentage are the parameters used most commonly to evaluate the foam separation performances and the former can reflect more the character of foam separation. It is well known that interfacial adsorption and foam drainage are two critical processes which determine the enrichment ratio. The two processes are significantly affected by system properties, operation conditions and equipment parameters, so researchers commonly preferred to improve the enrichment ratio by optimizing these factors [10–12]. The design of a new foam separation column is also an effective method to increase the enrichment ratio. Researches have designed many kinds of devices in the foam phase of foam column to enhance foam drainage, such as the spiral internal [13], the foam riser [14], the perforated plate [15] and cartridge filter [16]. Although these devices could enhance foam drainage, their application will be limited due to their complicated structure.

At present, most researchers only investigated foam drainage between the adjacent bubbles in the foam phase and neglected that between the bubbles and the column wall. In fact, the column wall should have an important effect on foam drainage. There have been some studies of the wall effect on the static foam drainage. Brannigan and De Alcantara Bonfim [17] investigated the wall effect of a vertical column using the forced drainage experiments. They found that the drainage velocity monotonously decreased with decreasing the column diameter when the diameter was smaller than 37.5 mm. It was pertinent to conclude that the drainage velocity on the wall was higher than that in the foam. Papara et al. [18] increased the column diameter larger than 37.5 mm in their experiments and observed more complex effects of the column wall on the free foam drainage. They, however, recognized that the wall effect would weaken with increasing the column diameter. Koehler et al. [19,20] gave microscopic descriptions of foam drainage on the column wall with modeling the liquid flow through single Plateau border. They defined two channels in the model: one is the interior channel, i.e. the Plateau border, formed by three intersecting films; the other is the exterior channel formed by two intersecting films and the column wall. Koehler et al. pointed out that the liquid velocity through the exterior channel was as large as seven times the liquid velocity through

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Nomenclature

Roman symbols

V_F	foam volume, mL
V_L	liquid volume contained in the foam, mL
V_{out}	volume of the foamate, mL
V_G	volume of air provided by the air compressor, mL
d_{32}	mean bubble diameter, mm
C_0	crystal violet concentrations in the initial loading solution, kg/m^3
C_f	crystal violet concentrations in the foamate, kg/m^3
C_e	crystal violet concentrations in the residual solution, kg/m^3
Q	total volumetric drainage velocity, m^3/h
N_{int}	numbers of the interior channel
N_{ext}	numbers of the exterior channel
q_{int}	volumetric drainage velocities in the interior channel, m^3/h
q_{ext}	volumetric drainage velocities in the exterior channel, m^3/h
j_g	rising velocity of bubble in the bulk liquid, m^3/h
j_{gw}	rising velocity of bubble near column wall, m^3/h

Greek symbols

ε_f	liquid holdup of the static foam
ε_{out}	liquid holdup out of the foam of the column

the interior channel when the liquid had low interfacial mobility. So it will be effective to use the wall effect to enhance foam drainage. However, all the investigations above were carried out for the static foam and the effect of gas flow was not considered. Moreover, these investigations have not been applied to improve foam separation performances.

According to the observations of channel drainage by Koehler, a novel and structurally simple foam separation column will be developed for investigating the effect of the column wall on the drainage of rising foam. Its schematic diagram is presented in Fig. 1 which illustrates that the cross internal is inserted in the foam phase. The cross internal can significantly increase wall contacted area with the foam, thus providing more exterior channels. An increase of exterior channels facilitates the release of the entrained liquid within the foam. The effect of column wall on the rising foam drainage was assessed by measuring the liquid holdup out of the column and bubble size using sodium dodecyl sulfate (SDS) as the research system.

Crystal violet (CV) is used extensively in textile dyeing industries [21] and has harmful effects on the environment [22,23]. Crystal violet can be removed by foam separation through the formation of dye-surfactant complexes with SDS. Therefore, the performances of the column with the cross internal were assessed by using CV as the model system and SDS as the collector.

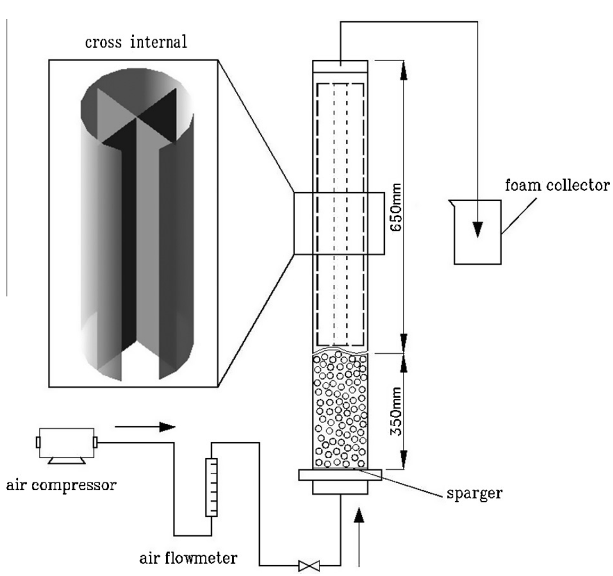

Fig. 1. Schematic diagram of a batch mode foam separation apparatus.

2. Materials and methods

2.1. Chemicals and analytical methods

Analytical sodium dodecyl sulfate and crystal violet were purchased from Sinopharm Chemical Reagent Co. Ltd. (China). The CV concentration was determined with UV/visible spectrophotometer (U-3010 Hitachi) at the maximum wavelength 586 nm [24]. The CV concentration was fixed at 10 mg/L in all experiments.

2.2. Equipment

Fig. 2 presents the foam column used in this study. The column was constructed from glass tube of 1000 mm high with an inner diameter of 55 mm. The cross internal made of transparent polypropylene plastic was 600 mm high and 0.3 mm thick. The cross internal was installed at the height of 350 mm from the bottom of column. The column with cross internal was served as the experimental column and the column without cross internal was served as the contrasted column. A gas sparger of lacunaris sintered glass was mounted at the column bottom. A rotameter (LZB-3WB, 60–600 mL/min, Wuhuan Instruments, China) was used to control air flow rate. The foam was directed to a collector using a collection spout fitted on the top of the column.

2.3. Measurement of the global liquid holdup of the static foam

The foam separation was carried out under the conditions of liquid loading volume 700 mL, initial SDS concentration 0.2 g/L, air

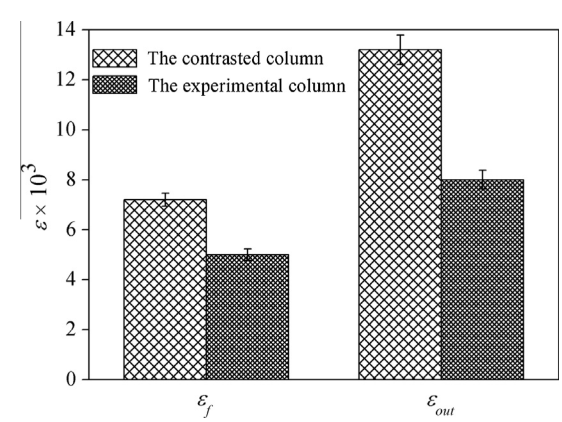

Fig. 2. Effects of the column wall on static foam drainage and rising foam drainage.