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Effective improvement of defoaming efficiency using foam breaker with synthetic sponge cylinders in foam fractionation

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For effectively improving the physical defoaming efficiency in foam fractionation, a new foam breaker with synthetic sponge cylinders was developed and its defoaming mechanism was analyzed. Due to synthetic sponge's high water absorption ability, it resulted in a large pressure difference inside and outside the liquid film to rapidly collapse the foam. The defoaming efficiency was studied on the basis of the effects of the type and number of synthetic sponge cylinders, SDS concentration, volumetric liquid fraction and volumetric air flowrate. The results show that the synthetic sponge cylinder with 0.23 ± 0.05 mm in mean pore diameter and 70.0 ± 0.5% in mean porosity had the highest defoaming efficiency and a larger number of synthetic sponge cylinders resulted in a higher defoaming percentage. Under suitable conditions, defoaming percentage of the new foam breaker with 4 of the optimal synthetic sponge cylinders reached 100.0%. Furthermore, the synthetic sponge cylinders had much higher defoaming efficiency, lower equipment cost, lower energy consumption and simpler preparation than perforated plates and paddle agitator. So the foam breaker with synthetic sponge cylinders is highly promising in industrial defoaming.

1. Introduction

Foam is a gas-in-liquid dispersion system which consists of a large number of tightly packed gas bubbles. It is generated from a surfactant solution by aeration, agitation or impact. The presence of foams in many industrial processes often has unwanted consequences such as the loss of target products and substrates, reduction in working volume of equipment and even environmental pollution [1]. For instance, during a process of fermentation, foams will result in bacterial contamination and the loss of culture mediums [2]. However, foams are desirable in foam flotation and foam fractionation, because they are used as separation media to separate minerals, metal ions, surfactants [3–5]. In these processes, foams must be collapsed to obtain the separated materials. Thus defoaming has been an essential operation unit.

At present, the common defoaming methods are divided into two types: chemical and physical. The chemical defoaming method denotes the addition of antifoaming agents into foams [6]. It has high defoaming efficiency and simple operation, but will affect the subsequent purification of the target products from the collapsed foam solutions. Particularly in the food and pharmaceutical industries, antifoaming agents will affect the safety of the products [7]. So, the physical defoaming methods which denote the use of mechanical force or ultrasonic are often the better choice [8,9]. They certainly will not cause secondary pollution, but have low defoaming efficiency, high equipment cost and high energy consumption. For overcoming these disadvantages, a column installed with perforated plates was developed as a foam breaker by Liu et al. [10]. This device considerably decreased the energy consumption for defoaming. However, a requirement for its high defoaming efficiency is that the foam flowing through the perforated plates must have a high speed. Furthermore, a high pressure was readily generated in the foam breaker. Thus extra energy consumption was still needed to speed the foam flow.

This work will develop a column installed with synthetic sponge as a new foam breaker to further improve the efficiency of physical defoaming and decrease its energy consumption. The synthetic sponge has a large number of hydrophilic groups and capillaries at its surface [11], so it deserves a strong ability of adsorbing water. Thus this material is considered to have a good defoaming ability by intensifying the liquid drainage of foams as soon as possible to accelerate bubble breakage. Furthermore,

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synthetic sponge has low price, free toxicity, soft texture and high elasticity [12], so it can be used to prepare internal components of different shapes to improve the defoaming efficiency.

In the present work, the defoaming mechanism of synthetic sponge will be firstly investigated. Secondly, the dependency of the defoaming efficiency on the porosity and the number of synthetic sponge cylinders, volumetric liquid fraction, SDS concentration and volumetric air flowrate will be investigated. Finally, the defoaming efficiency of synthetic sponge will be compared to that of the stirring foam breaker and the perforated plates to show the advantages of the new foam breaker.

2. Materials and methods

2.1. Materials

Sodium dodecyl sulfate (SDS) and sodium hydrate (NaOH) of analytical grade (99.9% purity) were purchased from Tianjin Fuchen Chemical Reagent Factory, China. Open-cell reticulated synthetic sponges were purchased from Tianjin Shuanglian Polymeric Sponge Factory, China and some of their structural parameters are presented in Table 1.

2.2. Experimental setup

Fig. 1 shows the schematic diagram of the experimental setup which consists of two unit operations, foam fractionation and defoaming. The foam fractionation column was constructed by a transparent plexiglass tube of 1000 mm in height and 50 mm in inner diameter. A gas distributor of sintered glass with 0.18–0.25 mm in pore diameter was mounted at the bottom of column. The feed solution was pumped by a peristaltic pump (YW03, Changzhou Yuanwang Fluid Co. Ltd., China) into the foam fractionation column. Air flowed through 6 mol/L NaOH solution in the gas-washing bottle to remove CO_2 before it was pumped into the foam fractionation column by an air compressor (ACO-318, Guangdong Haili Co. Ltd., China) to generate foams. The volumetric air flowrate was adjusted and monitored by a gas rotameter (LZB-3WB, 60–600 mL/min, Tianjin Meter Factory, China). The foam fractionation experiments were operated in a continuous model at room temperature 25 ± 2 °C and relative humidity 40 ± 5%. When the height of the foam-liquid interface was constant, the continuous foam fractionation reached a steady state. Then the foam from the foam fractionation column flowed into the foam breaker to be collapsed. The foam breaker consisted of a transparent plexiglass tube of 550 mm in height and 50 mm in inner diameter and several synthetic sponge cylinders of 500 mm in height and 15 mm in diameter. The synthetic sponge cylinders were fixed inside the tube by stainless steel wires.

2.3. Measurement of volumetric liquid fraction of foam out of the column

In a steady continuous foam fractionation process, the volumetric liquid fraction of the foam at the outlet of the foam fractionation column (ε) was determined as Eq. (1).

$$\varepsilon = \frac{Q_l}{Q_l + Q_g} \times 100\% \tag{1}$$

where Q_l (mL/min) and Q_g (mL/min) are the volumetric liquid flowrate and volumetric air flowrate in the foam out of the foam fractionation column, respectively. Q_l was calculated as Eq. (2) when the continuous foam fractionation reached a steady state, corresponding to a constant height of the foam-liquid interface.

$$Q_l = Q_o - Q_r \tag{2}$$

where Q_o (mL/min) and Q_r (mL/min) are the volumetric flowrates of the feed solution and residual solution, respectively. Q_r was calculated as Eq. (3).

$$Q_r = \frac{dV_r}{dt} \tag{3}$$

where t (min) is time, $t = 5.0$ min; V_r is the volume of the residual solution collected in 5.0 min.

In the experiments, Q_o and Q_r were adjusted and correspondingly, the height ratio of foam vs liquid were changed. Then the foams with different volumetric liquid fractions were obtained when the continuous foam fractionation reached a steady state. Note that in all the experiments, the relative pressure drop of the air was limited to lower than 5.0% by adjsuting the height of the foam-liquid inerface so that the air compressibility could be neglected, so Q_g was considered as the one monitored by the gas rotameter.

2.4. Measurement of SDS concentration

The SDS concentration was measured by the methylene blue spectrophotometric method at the maximum absorption wavelength of 652 nm using a UV–vis spectrophotometer (725N, Shanghai Precision & Science Instrument Co. Ltd., China) [13]. The linear fitting equation is $A = 66.998C + 0.022$, $R^2 = 0.99909$, where A is absorbance; C is SDS concentration; R is linear correlation coefficient.

2.5. Measurement of rising velocity of the foam-liquid interface

The measurement of rising velocity of the foam-liquid interface was carried out in the foam breaker in Fig. 1. Firstly, the same gas distributor as the one in the foam fractionation column was installed at the bottom of the foam breaker. Secondly, 100 mL SDS solution of 0.60 g/L was loaded in the foam breaker with 0–4 synthetic sponge cylinders of type A. Thirdly, air was bubbled into the foam breaker by using the ACO-318 air compressor at 200 mL/min controlled by the LZB-3WB gas rotameter for 2 min to generate a foam. Fourthly, the variation of the height of the foam-liquid interface (H, mm) with time (t, s) was recorded by a camera (FDR-AXP35, Sony, Japan) as soon as the aeration was stopped. Fifthly, the recorded video was treated by a free video editor to obtain the data of H. Finally, the first-derivative of the vairation of H with t was calculated by using Origin 8.0 software (Origin-Lab Corp., USA) to obtain the rising velocity of the foam-liquid interface (j_d, mm/s), defined as Eq. (4).

$$j_d = \frac{dH}{dt} \tag{4}$$

2.6. Measurement of bubble radius

Bubble radius was measured as the method of Li et al. [14]. Firstly, a camera (Nikon CooLPIX P6000) was used to obtain the photographs of the foam at the top of the foam fractionation

Table 1
Bulk density, mean pore diameter and mean porosity of open-cell reticulated synthetic sponges used in the experiments.

Type	Bulk density (kg/m^3)	Mean pore diameter (mm)	Mean porosity (%)
A	55.0 ± 0.2	0.23 ± 0.05	70.0 ± 0.5
B	42.2 ± 0.2	0.33 ± 0.08	76.0 ± 0.5
C	25.4 ± 0.1	0.52 ± 0.08	86.0 ± 0.5