APPLICATION OF NONFOAMING BUBBLE SEPARATION TO ENRICHMENT OF DILUTE DYE SOLUTION

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Introduction

The method called "bubble separation" can be classified into two categories, that is, "foam separation" and "nonfoaming bubble separation"⁷⁾. Foam separation has been widely used in various industrial fields such as ore flotation^{3, 5)} and waste water treatment⁶⁾. On the other hand, nonfoaming bubble separation is a rather new and undeveloped technique which was first proposed by Lemlich and his co-workers^{2, 4)} in the early 60s. They reported that the local concentration of dye in an aerated column filled with its dilute solution increased almost exponentially with the height from the column bottom at the steady state⁴⁾. This fact suggests that if an appropriate technique to separate the gas-liquid interface from the bulk liquid is available, the enrichment of surface-active substances such as a dye should be achievable, even though the dye's concentration is below that needed for foaming.

When a solution in a column is aerated, a large number of fine droplets generated at the liquid-atmosphere interface can be observed. These droplets are originated from the burst of ascending bubbles through the liquid and they should include most of the bubble surface where surface-active substances are enriched. In this paper, the authors will propose a new enriching method for a dilute solution of surface-active substance using a bubble column equipped with a droplet collector on the top.

1. Experimental

An experimental setup is shown in **Fig. 1**. A bubble column of 0.044 m in inside diameter and 0.36 m in height was normally employed, but columns of 0.7 and 1.03 m in height were also used, when necessary. The columns were made of transparent acrylic resin to facilitate observation of the motion of bubble swarms. A sintered glass filter, which had pores of 10 - 15 μm in mean diameter, was installed as a gas distributor at the bottom of the columns. A droplet collector shown in **Fig. 2** was installed at the top of the column. It was made of transparent plastic and consisted of a conical upper section with a cone angle of 75° and a cylindrical lower section with a diameter of 50 mm and a height of 32 mm. A suction tap of stainless steel

pipe (0.3 mm in inside diameter) was attached to the top of the cone and it was connected to a reservoir for droplet recovery. To minimize droplet drying, four glass tubes were installed in the wall of the cylindrical part to induce humidified air.

All experiments were operated as batch runs with respect to the liquid. A crystal violet (purchased from Wako Pure Chemical Industry) solution was prepared at the desired concentration and it was charged into the column. Then, air was dispersed into the column and aspiration for droplet collection was started. A lot of fine droplets generated by bubble bursts at the liquid surface were induced into a sampling reservoir by the aid of an air stream through a vacuum aspirator. To avoid the error caused by sample drying, another reference reservoir was connected with the sampling one in series. An equal amount of distilled water was placed in both. The volume of sampled liquid was calibrated by the volume decrease of precharged water in the reference. Each run was conducted for 30 minutes. The concentration of crystal violet (CV) solution was measured spectrophotometrically at 600 nm. Gas holdup was determined by measuring the difference in static pressure between the clear and aerated liquids using a differential pressure transducer. All experiments were carried out at room temperature and under atmospheric pressure.

2. Results and Discussion

Figure 3 shows the vertical profiles of volumetric flow rate of droplets for a constant CV concentration of $1 \times 10^{-5} \text{ kg/dm}^3$ and various superficial gas velocities. The flow rates were measured at six vertical positions specified by H , which denotes the distance between the liquid surface and the entrance of the suction tap. Straight solid lines with a fixed and common intercept at the H -axis were determined as minimizing every sums of the square deviation between the lines and the corresponding data points. The intercept, $7.32 \times 10^{-2} \text{ m}$, is the maximum flight height of a droplet. The q -axis intercepts of the lines represent the intrinsic volumetric flow rate, q_0 , of droplets at the liquid interface.

Figure 4 shows the variation of q_0 or q_0/S_b with U_g .

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Fig. 1 Schematic diagram of experimental setup for nonfoaming adsorptive bubble separation

Fig. 2 Detailed drawing of droplet collector

where S_b denotes the surface area of bubbles rising through the column per unit time. It was determined from

Fig. 3 Axial profiles of volumetric flow rate of droplets, q . The experiments were conducted with 1×10^{-5} kg/dm³ crystal violet at various superficial gas velocities

Fig. 4 Change in volumetric flow rate of droplets, q_0 , at the liquid surface estimated from Fig. 3 and q_0/S_b as a function of superficial gas velocity

$$S_b = 6A\varepsilon(1 - \varepsilon)^{4.65} \left\{ (4 / 225)(\rho_L - \rho_G)^2 g^2 / (\mu_L \rho_L) \right\}^{1/3} \quad (1)$$

This equation was derived from the assumption that bubbles are homogeneous spheres and their terminal rising velocity can be calculated by Allen's equation¹⁾. Shirai's equation⁸⁾ was employed for voidage compensation. In this figure, the q_0/S_b value appears to be almost constant in the region of $U_g < 4 \times 10^{-4}$ m/s. In other words, burst bubbles at the liquid surface should generate such droplets that the sum of their volume is proportional to the surface area of the bubbles.

The enriching experiments for CV solutions in various initial concentrations were conducted at a constant superficial gas velocity of 5.37×10^{-4} m/s. The results are

Fig. 5 Effect of initial concentration of crystal violet, C_i , and column height on droplet concentration, C_{tr}

given in Fig. 5 where C_i and C_{tr} represent the CV concentrations of the solution initially charged to the column and the droplets collected at the position $H = 0.02$ m from the liquid surface, respectively. As seen in the figure, the data are apparently classified into three groups. The broken curves for the data groups show the regression lines determined by the least squares method. The slopes of regression lines in normal plots of C_{tr} against C_i were 12.0, 0.718 and 2.78 in the concentration regions of $C_i < 2 \times 10^{-6}$ kg/dm³, $2 \times 10^{-6} < C_i < 1 \times 10^{-5}$ kg/dm³ and $C_i > 1 \times 10^{-5}$ kg/dm³, respectively. As the slopes correspond to the enriching ratio of CV solution, it is apparent that the enriching operation in the low concentration region is more efficient than in the other regions. In high concentration regions, the accumulation of a foam layer at the liquid-atmosphere interface increased with the increase of CV concentration, and then droplets were generated from the liquid film at the top of the foam layer. Such a phenomenon caused an increase in enriching ratio and a decrease in droplet recovery (Fig. 4), as compared with the intermediate region.

In nonfoaming adsorptive bubble separation, the enriching effect is considered to be influenced by four factors: (1) adsorption density of surface-active substances at the bubble-liquid interface, (2) production rate of the bubble-liquid interfacial area, (3) separation efficiency of

the bubble-liquid interface from bulk liquid as droplets and (4) volumetric flow rate of droplets, that is, the amount of bulk liquid entrained within the bubble-liquid interface. Factor (1) is closely related to the physico-chemical characteristics of objective substances, while factors (2), (3) and (4) should be a function of liquid properties, operating conditions and the process characteristics of the bubble column. Among them, factor (2) mainly relates to the processing rate, whereas factors (3) and (4) should greatly influence the degree of enrichment. For obtaining more enriched droplets, it is desirable to remove as much of the bubble surface as possible, while remaining as little of the entrained bulk liquid as possible. More detail and quantitative discussion about the above factors will be made in a paper to follow.

Nomenclature

A	= cross sectional area of bubble column	[m ²]
C_i	= initial concentration in bubble column	[kg/dm ³]
C_{tr}	= entrained droplet concentration	[kg/dm ³]
g	= gravitational acceleration	[m/s ²]
H	= distance between liquid surface and suction tap	[m]
q	= volumetric flow rate of droplets at H	[m ³ /s]
q_0	= volumetric flow rate of droplets at liquid surface estimated in Fig. 3	[m ³ /s]
S_b	= production rate of bubble surface	[m ² /s]
U_g	= superficial gas velocity	[m/s]
ε	= gas holdup	[-]
μ_L	= liquid viscosity	[kg/m s]
ρ_G	= gas density	[kg/m ³]
ρ_L	= liquid density	[kg/m ³]

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