Korean J. Chem. Eng., 17(5), 597-599 (2000)

Development of Bubble Column for Foam Separation

Yoshiyuki Bando†, Takahiro Kuze, Tatsuya Sugimoto, Keiji Yasuda and Masaaki Nakamura

Department of Chemical Engineering, Nagoya University, Furocho, Chikusaku, Nagoya 464-8603, Japan
(*Received 26 May 2000 • accepted 13 June 2000*)

Abstract−The foam separation of metal in model wastewater is performed by using two different bubble columns in a continuous operation mode. The equipment and operation conditions are changed, and the foam flow rate and metal concentration in foam flow are measured. The foam flow ratio (the ratio of foam flow rate to the inlet one) increases with increasing gas velocity, with decreasing liquid velocity, with decreasing foam layer height and with decreasing metal concentration in model wastewater. Metal enrichment (the ratio of metal concentration in foam flow to that in inlet flow) shows the reverse tendencies. When a draft tube is inserted in the bubbling layer, the foam flow rate decreases. The enrichment is strongly governed by the foam flow ratio. Since the foam flow ratio is adjusted by means of the equipment and operation conditions, the metal concentration in foam flow is controlled to be a desired value.

Key words: Foam Separation, Bubble Column, Wastewater Treatment, Metal Removal, Metal Adsorption

INTRODUCTION

Treatment of wastewater containing metal has become very important. From the viewpoints of environment and resources, it is necessary to separate and recover the metal in wastewater. Foam separation, which utilizes metal adsorption on the bubble surface, is considered to be one of the most useful techniques, especially when the metal concentration in wastewater is relatively low.

Although there have been many studies on foam separation, the objective of early studies was the removal of surfactant from domestic wastewater. Recently, since foam separation has been clarified to be effective for metal removal, the foam separation of metal has become a research focus. Kubota et al. [1977] and Moussavi [1994] have performed the foam separation of metallic ions. Choi and Ihm [1988] have carried out unique foam separation, *i.e.*, precipitate floatation and adsorbing colloid floatation. Hiraide and Mizuike [1984] have applied foam separation to a metallic analysis for dilute solution. The adsorption characteristics in foam separation have also been examined. Shirotsuka and Ishiwata [1973] and Kato and Nakamori [1976] have explained the adsorption mechanism on the basis of Langmuir's adsorption isotherm. Kato et al. [1992] have investigated the surface excess of metallic ion. Suzuki and Maruyama [2000] have considered foam separation using proteins as a foaming regent. These studies described above are based on physical and surface chemistries. However, there are few studies from the viewpoint of reactor engineering. Grieves and Wood [1964] have studied the influence of the position of feed introduction on foam fractionation.

In this study, two different bubble columns were used and the foam separation of metal was performed. The effects of equipment and operation conditions on the foam generation and separation performance were examined.

EXPERIMENTAL

An outline of the experimental apparatus is shown in Fig. 1. The columns were made of transparent acrylic resin and the inside diameter was 0.100 m. The column height was changed from 1.30 to 1.45 m and the bubble free liquid height was adjusted to be 1.00 m. The gas sparger was a nozzle with 3 mm diameter. The liquid outlet was located at the column bottom. In the case of countercurrent bubble column (Fig. 1a), the gas sparger was located at 0.10 m above the column bottom. The liquid sparger was a nozzle with

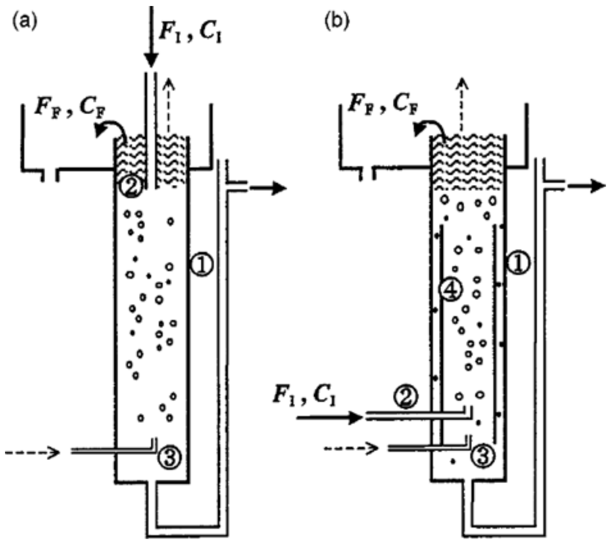

Fig. 1. Outline of experimental apparatus (a) countercurrent bubble column (b) bubble column with draft tube.
1. Bubble column
2. Liquid sparger
3. Gas sparger
4. Draft tube
➡ Liquid flow
--> Gas flow

†To whom correspondence should be addressed.
E-mail: bando@nuce.nagoya-u.ac.jp
This paper was presented at The 5th International Symposium on Separation Technology-Korea and Japan held at Seoul between August 19 and 21, 1999.

25 mm diameter and located near the liquid surface. In the case of bubble column with draft tube (Fig. 1b), the length and inside diameter of draft tube were 0.80 and 0.076 m, respectively. Both the clearances below and above the draft tube were 0.10 m. The gas sparger was located at 0.05 m above the lower end of draft tube and the gas was sparged into the draft tube. The liquid sparger was a nozzle with 5 mm diameter and located at 0.10 m above the lower end of draft tube, *i.e.*, at 0.05 m above the gas sparger.

The metal to be separated was iron in $FeCl_3$ and the concentration was 0.020 kg/m^3. The surfactant was sodium lauryl sulfate and the concentration was 0.15 kg/m^3, which is much lower than the critical micelle concentration (about 3.0 kg/m^3).

The experiments were performed in a continuous operation mode. After the flow pattern became stable, the liquid discharged from the outlet was sampled and the flow rate was measured. The metal concentration in discharged liquid was analyzed by using an atomic absorption spectrometer (Shimazu, AA-6400). The foam flow rate and metal concentration in foam flow were calculated from the material balance.

RESULTS AND DISCUSSION

1. Countercurrent Bubble Column

The effects of gas and liquid velocities on the foam flow rate and metal concentration in foam flow are shown in Fig. 2. The ordinates are the foam flow ratio (the ratio of foam flow rate to the inlet one), and the enrichment (the ratio of metal concentration in foam flow to that in inlet flow). The velocity in this study is the superficial one based on the cross-sectional area of column. As the gas velocity becomes higher, the foam flow ratio increases and the enrichment decreases. This is because the amount of liquid entrained between bubbles becomes larger. When the liquid velocity becomes high, the foam flow ratio decreases at the relatively high gas velocity.

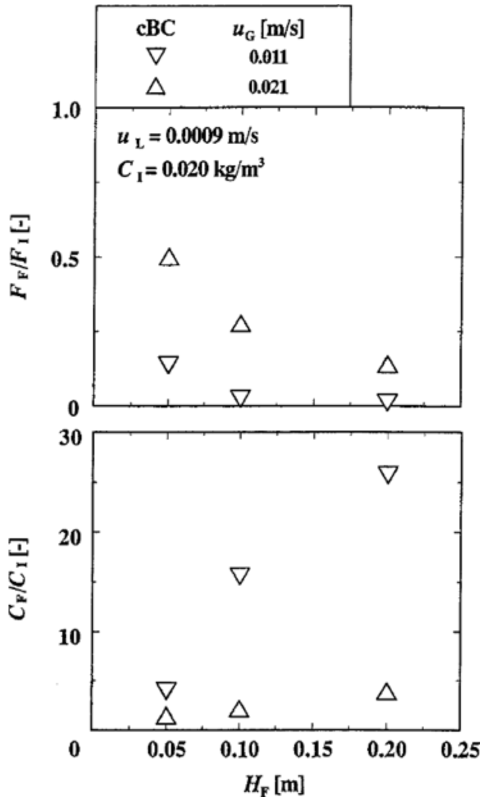

Fig. 3. Effect of foam layer height on foam flow ratio and enrichment in case of countercurrent bubble column.

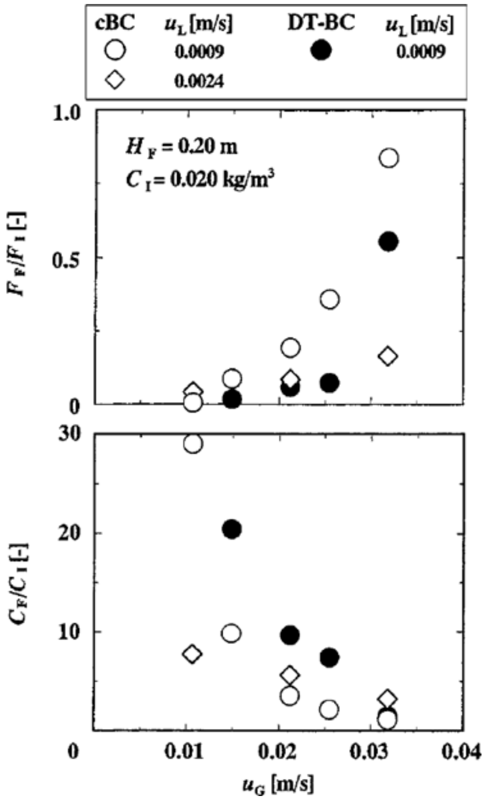

Fig. 2. Effects of gas and liquid velocities on foam flow ratio and enrichment.

The effect of foam layer height on the foam flow ratio and enrichment is shown in Fig. 3. In this experiment, the bubbling layer height in sparging gas is fixed and the column height is changed. As the foam layer becomes higher, the foam flow ratio decreases and the enrichment increases. This is because in the relatively high foam layer, a part of liquid entrained between bubbles flows downward by gravity. It has been reported that the liquid holdup is higher in the lower part than in the upper part of the foam layer [Cutting, 1989].

The effect of metal concentration in model wastewater on the foam flow ratio and enrichment is shown in Table 1. As the metal concentration becomes high, the foam flow ratio decreases and the enrichment increases. The reason is considered as follows: as the metal concentration becomes higher, more surfactant molecules

Table 1. Effect of metal concentration at inlet on foam flow ratio and enrichment in case of countercurrent bubble column

C_I [kg/m^3]	0.020	0.040
F_F/F_I [-]	0.19	0.07
C_F/C_I [-]	3.58	4.88

u_G=0.021 m/s, u_L=0.0009 m/s, H_F=0.20 m

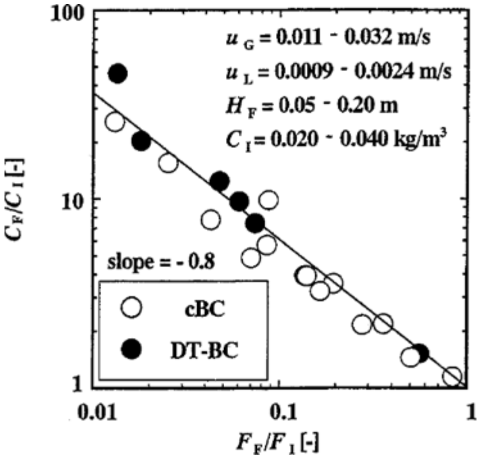

Fig. 4. Plot of enrichment against foam flow ratio.

bond with metal and the contribution of surfactant to foaming becomes smaller. From this result, it is predicted that, when the amount of surfactant is less than the chemical equivalent value for the bond between metal and surfactant, the foam flow disappears.

2. Bubble Column with Draft Tube

The bubble column with draft tube was used to change the flow pattern in bubbling layer and the bubble size at interface between bubbling and foam layers. The results are shown in Fig. 2. When the gas velocity is constant, the foam flow ratio is lower and the enrichment is higher than those in the countercurrent bubble column. The reason is considered as follows: the small bubbles entrain much of bulk liquid into the foam layer. By inserting the draft tube, small bubbles are recirculated into the downcomer due to the liquid circulation flow, and as a result small bubbles hardly reach the interface between bubbling and foam layers. In addition, due to no liquid sparger in the foam layer, the foam stability decreases [Kuze et al., 1999] and as a result, the foam flow rate decreases.

3. Relationship between Foam Flow Ratio and Enrichment

For both the bubble columns, the enrichment is plotted against the foam flow ratio as shown in Fig. 4. It is found that the enrichment depends strongly on the foam flow ratio regardless of the column type, gas and liquid velocities, foam layer height and initial metal concentration. From this plot, the following equation is obtained.

$$C_F/C_I=(F_F/F_I)^{-0.8} \qquad 0.01\le F_F/F_I\le 1 \tag{1}$$

The foam flow rate is easily adjusted by means of the equipment and operation conditions. Therefore, it is considered that the enrichment is controlled to be a desired value.

CONCLUSION

Foam separation of metal in model wastewater is performed by using two different bubble columns in a continuous operation mode. The following facts are clarified.

1. The foam flow ratio increases with increasing gas velocity, decreasing liquid velocity, decreasing foam layer height and decreasing metal concentration in model wastewater. The enrichment shows the reverse tendencies.

2. The foam flow ratio is affected by the change in bubble size.

3. The enrichment depends on the foam flow ratio and the relation is given by Eq. (1). The enrichment is easily controlled by the equipment and operation conditions.

NOMENCLATURE

C : concentration of separated material [kg/m^3]
F : flow rate [m^3/s]
H_F : foam layer height [m]
u_G : superficial gas velocity based on cross-sectional area of column [m/s]
u_L : superficial liquid velocity based on cross-sectional area of column [m/s]

Subscripts

F : foam flow
I : feed flow

REFERENCES

Choi, S. J. and Ihm, S. K., "Removal of Cu(II) from Aqueous Solutions by the Foam Separation Techniques of Precipitate and Adsorbing Colloid Flotation," *Sep. Sci. Technol.*, **23**, 363 (1988).

Cutting, G. W., "Effect of Froth Structure and Mobility on Plant Performance," Mineral Processing and Extractive Metallurgy Review, **5**, 169 (1989).

Grieves, R. B. and Wood, R. K., "Continuous Foam Separation: the Effect of Operating Variables on Separation," *AIChE J.*, **10**, 456 (1964).

Hiraide, M. and Mizuike, A., "Bubble Separation in Analytical Chemistry," *Bunseki*, **12**, 902 (1984).

Kato, K. and Nakamori, I., "Adsorptive Characteristics of Ion in Foam Separation Techniques," *Kagaku Kogaku Ronbunshu*, **2**, 272 (1976).

Kato, K., Ishikawa, T., Kasahara, Y. and Miyaki, S., "Method of Estimating Surface Excess of Metal Ion in Foam Separation," *J. Chem. Eng. Japan*, **25**, 561 (1992).

Kubota, K., Hayashi, S. and Nishijima, M., "The Removal of Sodium and Cadmium Ions from Dilute Aqueous Solutions Using Foam Separation," *Kagaku Kogaku Ronbunshu*, **3**, 142 (1977).

Kuze, T., Chaya, M., Yasuda, K., Bando, Y. and Nakamura, M., "Effects of Equipment and Operation Conditions on Foam Generation," Procd. of 32th Autumn Meeting of Soc. Chem. Eng. Japan, F120 (1999).

Moussavi, M., "Foam Fractionation of Negative Ions," *Sep. Sci. Technol.*, **29**, 1087 (1994).

Shirotsuka, T. and Ishiwata, M., "Studies on Bubble Fractionation—Adsorption Rate and Elimination of D.B.S.—," *Kagaku Kougaku*, **37**, 397 (1973).

Suzuki, Y. and Maruyama, T., "Effects of pH and Coexistent Substances on the Foam Formation of a Protein Solution," *J. Japan Soc. Water Environment*, **23**, 108 (2000).