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Short Communication

Effect of surfactant addition on removal of microbubbles using ultrasound

Daisuke Kobayashi [a,*], Yoshiyuki Hayashida [b], Kazuki Sano [b], Koichi Terasaka [a]

[a] Department of Applied Chemistry, Faculty of Science and Technology, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan
[b] School of Science for Open and Environmental Systems, Graduate School of Science and Technology, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan

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A B S T R A C T

It is difficult to control the bubble in a liquid by the external operation, because the behavior of the bubble is controlled in buoyancy and flow of liquid. On the other hand, microbubbles, whose diameter is several decades μm, stably disperse in static liquid because of their small buoyancy and electrical repulsion. When an ultrasound, whose frequency was 2.4 MHz, was irradiated, the milky white microbubbles suspended solution became rapidly clear. In this study, the effects of surfactant addition on the removal of microbubbles from a liquid in an ultrasonic field were investigated. The efficiency of removal of microbubbles decreased with surfactant addition. Surfactant type influenced the size of agglomerated microbubbles, and the efficiency of removal of microbubbles changed. The surface of microbubble was modified by surfactant adsorption, and the steric inhibition influenced the removal of microbubbles.

1. Introduction

The unit operation including bubbles in a liquid has been used in a chemical industrial process such as chemical reactor, heat exchanger, and aerating tank. Especially, gas absorption operation is used in a wide area for separation and recovery of required element in a gas. The device design to improve the rate of gas absorption has been investigated.

On the other hand, novel technology using microbubbles, whose diameter is between 10 and 60 μm in a liquid, has been established in aquaculture, waste water treatment and medical application treatment. Microbubble has useful characteristics such as large gas–liquid interfacial area, long resistance time in a liquid and high gas dissolution rate. It is advantageous for chemical process with gas–liquid contact operation. In spite of above introduced merits, the application of microbubbles in chemical industrial process has not been proceeded, because of the difficulty of controlling microbubbles in a liquid.

It is generally difficult to control the bubble in a liquid by the external operation, because the behavior of the bubble is controlled in buoyancy and flow of liquid. Especially, microbubbles, whose diameter is several decades μm, stably disperse in static liquid for long time. Therefore, it is important to develop a microbubble separation technology.

In our previous study, rapid microbubble removal technology using ultrasound is proposed [1]. When an ultrasound, whose frequency is 2.4 MHz, is irradiated, the milky white microbubbles suspended solution becomes rapidly clear. From the results of microscopic visualization, microbubbles forms agglomerates by Bjerknes force and are rapidly removed upward. In addition, the possibility of controlling not only agglomeration and coalescence behavior of microbubbles, but also their rise velocity in a liquid by suitable setting of solution and ultrasonic irradiation conditions is suggested [2].

Ultrasound is suggested to be a useful method for removal of microbubbles from a liquid. However, it is important to investigate the effects of adsorption of the contamination to the microbubbles' surface on dynamic behavior, because the liquid phase is the non-purification system in the many actual industrial plants. It is generally known that a rise velocity of spherical bubble in a contaminated liquid is much smaller than that of a bubble in a pure liquid. Takagi et al. have reported that Marangoni effect due to the variation of surface tension along the bubble surface is analyzed both experimentally and numerically [3]. And, the effects of a surfactant on a single ascending bubble motion and its surrounding liquid motion were investigated by visualization method using a high-speed video camera [4]. On the other hand, there are several reports about the effects of ultrasound on coalescence of bubbles [5,6].

* Corresponding author. Address: Department of Industrial Chemistry, Faculty of Eniginnering, Tokyo University of Science, Tokyo 162-8601, Japan. Tel.: +81 3 5228 8310; fax: +81 3 5261 4631.

E-mail address: dkobayashi@ci.kagu.tus.ac.jp (D. Kobayashi).

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In this study, the effects of surfactant addition on the removal of microbubbles from a liquid in an ultrasonic field were observed by some visualization techniques. Firstly, the effects of 3 kinds of surfactants of which the ionicity differs on removal of microbubbles were observed by macroscopic visualization. Secondary, the dynamic behavior of microbubbles in the presence of surfactant was observed by microscopic visualization. The purpose of this study was the investigation of the effects of surfactant on agglomerate behavior of microbubbles in an ultrasonic field.

2. Experimental

2.1. Formation of ultrasonic defoaming equipment

Fig. 1 shows the experimental apparatus to observe the removal of microbubbles under direct ultrasonic irradiation. The bubble column which made of transparent acrylic resin has inner diameter and height were 0.05 m and 1.00 m, respectively. The ultrasonic generator (HM-303N, Honda Electronics), whose frequency is 2.4 MHz, was set at the bottom. The outer diameter of ultrasonic generator was 48 mm, and the acoustic intensity estimated by calorimetry was about 2.1 W/cm^2. Microbubble suspension was prepared in the bubble column using the microbubble generator (OM4-GP-040, Auratec) by a pressurized dissolution method, and the temporal change of the boundary position from the bottom, h, due to rising microbubbles was observed using a digital video camera (GZ-MG575, Victor).

2.2. Removal of microbubbles using ultrasonic irradiation

Ion exchanged water added with 3 kinds of surfactants of sodium dodecyl sulfate (SDS), cetyltrimethylammonium bromide (CTAB), and polyoxyethylene sorbitan monolaurate (Tween 20) of which the ionicity differs was used as liquid phase, and air was used as gas phase. Table 1 shows the physical properties of surfactants using this study. The concentration of surfactant, C_s, was changed between 1.0×10^{-5} mol/L and 1.0×10^{-3} mol/L.

The size distribution of the microbubble was measured using a laser diffraction particle size analyzer (SALD-7100, Shimadzu). Fig. 2 shows the typical bubble size distribution produced using the microbubble generator. The average diameter and standard deviation of the bubbles were 28.0 μm and 12.8 μm, respectively. The bubble size did not depend on the surfactant addition in this study. The size of microbubble was also measured by the results of microscopic visualization described in Section 2.3. The size of microbubble was in the range from 20 μm to 40 μm. By the comparison of results of laser diffraction method and microscopic visualization method, the bubble diameter was almost same.

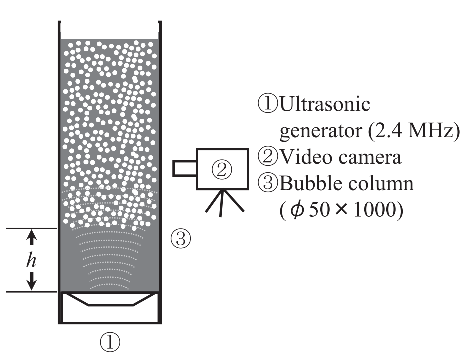

Fig. 1. The experimental setup of removal of microbubbles using direct ultrasonic irradiation.

Table 1
Physical properties of surfactants.

Surfactant	Ionization	M.W.	CMC (mol/L)
SDS	Anionic	288.4	8.0×10^{-3}
CTAB	Cationic	364.5	9.2×10^{-4}
Tween20	Non-ionic	1227.5	9.5×10^{-4}

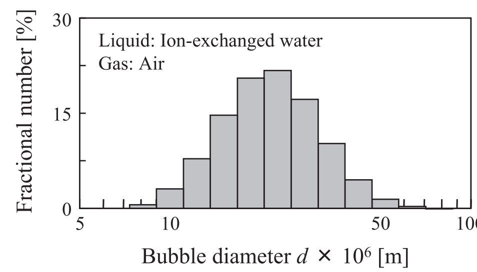

Fig. 2. Bubble size distribution.

2.3. Microscopic agglomeration behavior of microbubbles under ultrasonic field

Fig. 3 shows the experimental setup to observe the microscopic behavior of microbubbles under indirect ultrasonic irradiation. The thin observation cell which made of transparent acrylic resin has length, width and height were 8 mm, 30 mm and 250 mm, respectively. The microscopic behavior of microbubble suspension in the observation cell was observed using highspeed video camera (Motion Scope, Red Lake) attached with microscopic zoom lens (VH-Z25, Keyence).

The ultrasonic generator which was identical as shown in Section 2.1 was submerged on the bottom of the water bath. The thin observation cell made of transparent acrylic resin was set 100 mm above the ultrasonic generator, and the distance between bottom of the cell and observation position was set 200 mm. Before indirect ultrasonic irradiation, microbubble suspension was prepared in the thin observation cell using the microbubble generator. Ion exchanged water added with surfactant which was identical as shown in Section 2.2 was used as liquid phase, and air was used as gas phase. The concentration of surfactant was 1.0×10^{-4} mol/L.

3. Results and discussions

3.1. Removal of microbubbles using ultrasonic irradiation

3.1.1. Analysis of macroscopic visualization

Fig. 4 shows a typical series of snap shots of microbubble removal from SDS aqueous solution with ultrasonic irradiation. In

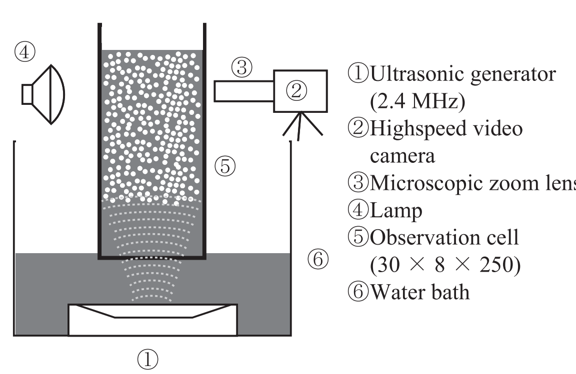

Fig. 3. Experimental setup of microscopic behavior of microbubbles.