LABORATORY EXPERIMENTS OF BUBBLE FORMATIONS AND BEHAVIORS IN SURFACTANT SEAWATER

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ABSTRACT

Surfactant concentration in seawater affects heat and gas exchanges between atmosphere and ocean via formations of air-bubbles during wave-breaking process as surfactant modifies surface tension to define bubble size. However, this effect to dynamics of bubble flows has poorly understood.

This paper presents the surfactant effects on geometric and kinematic features of bubble plumes and residual surface foams observed in laboratory experiments using backlit image measurements. We found the both bubble size distributions in surfactant water and seawater are well approximated by a lognormal distribution, while the bubbles in pure water deviate from the distribution. We also found analogous features in mean diameter, population and terminal velocity of bubbles in the surfactant and sea waters. The behaviors of coalescence and collapse of buoyant residual foams on a still water surface highly depend on the surfactant concentration. Our findings may contribute to understand mechanical processes of aeration and degassing in regional and seasonal variations of surfactant concentration depending on oceanic biological activity.

Keywords: surfactant, bubble, foam

1. INTRODUCTION

In a surf zone, air bubbles are entrained into the bulk seawater and transported to depths by turbulent carrier flows in an early stage of breaking process, while buoyant behaviors of bubbles agitate the surrounding seawater to modify the turbulent flows in a later stage, and finally come up to the ocean surface for forming residual foams remaining for long time (Watanabe et al. 2005). The series of bubble entrainment and degassing processes have multiple roles to enhance gas, heat and momentum exchanges between atmosphere and ocean, through gas dissolution from the entrained bubbles (Callaghan et al. 2013, Niida and Watanabe 2018), evaporative cooling on the foam (Marmorino and Smith 2005), and energy dissipation owing to bubble drag (Lamarre and Melville 1991). As surfactant of seawater is an important parameter to define surface tension, the bubble formation and behaviors may be modified by the surfactant concentration. Since concentration of surfactant in seawater, depending on oceanic biological activity, exhibits regional and seasonal changes (Wurl et al. 2011), the effects of surfactant concentration to bubble dynamics may be parameters to define local air-sea transport process owing to oceanic aeration.

In order to identify dynamics of surfactant bubbles and foams, in this study, we investigated surfactant effects on geometric and kinematic features of bubble plumes and residual surface foams observed in laboratory experiments using high-resolution backlit image measurements.

2. EXPERIMENTS

Two types experiments with different methods to create bubbles were performed in this study; experiments for (a) needle-generated bubbles and (b) bubbles generated under circular liquid jet (see figure 1 *a*). In experiment (a), steady air flow was sent to a submerged needle, fixed at bottom of a water tank, for generating a bubble plume. In (b), steady water jet was released from a cylindrical pipe into a still water stored in a tank. The free-surface of a cavity, formed around the impinging jet, was breakup for producing bubbles. Five experimental cases with different surfactant concentration were conducted for each experiment; distilled water (0% surfactant), 200 μg/*l* surfactant concentration, 400 μg/*l*, 800 μg/*l*, and artificial seawater. A LED backlit panel was installed behind a transparent rear wall for the both experiments, and shadow images of bubbles were recorded by a high-speed video camera (see figure 1 *b*). The surface locations of bubbles were determined by

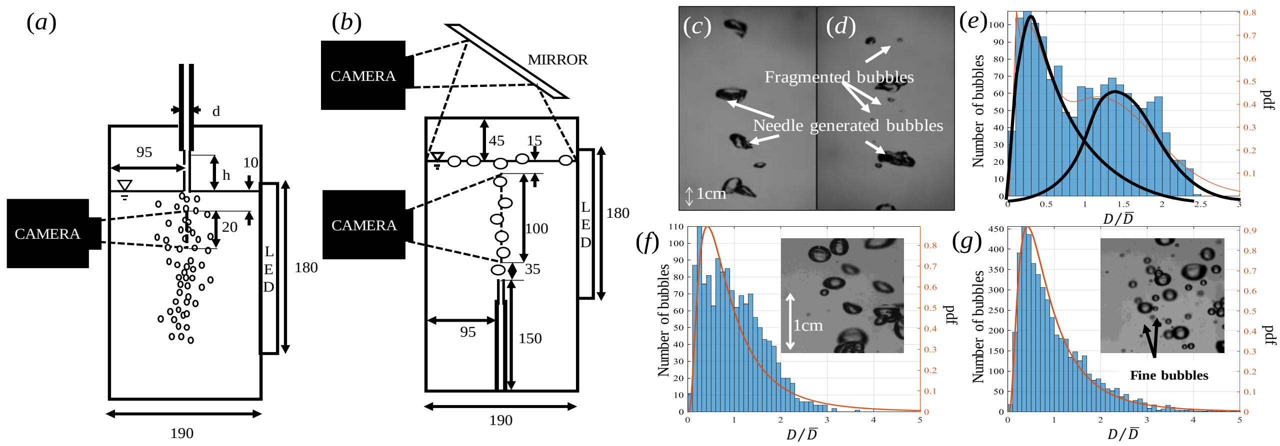

Figure 1. Experimental set up for (*a*) needle-generated bubbles, and (*b*) bubbles generated under cylindrical liquid jet (unit: mm). Backlit images of needle-generated bubbles for (*c*) distilled water and (*d*) 400 µg/*l* concentration water, (*e*) histogram of the needle-generated bubble size (400 µg/l), histograms of the jet-induced bubble size for (*f*) distilled water and (*g*) 400 µg/*l* concentration water

an edge detection technique based on the level-set method (Watanabe and Ingram 2015). The equivalent circle diameters of the detected bubbles were used as the representative bubble size, and the bubble velocity was estimated by tracking centers of the bubbles over sequential images.

3. RESULTS

3.1 Needle-generated bubbles

We observed from experiment (a) that large bubbles govern the size distribution of needle-generated bubbles in distilled water, while population of tiny bubbles, created by breakup of larger ones, increase with the surfactant concentration (see figure 1 *c*, *d*). The size distribution of the fragmented tiny bubbles follows lognormal distribution, while the Gaussian approximates the larger needle-generated bubbles (figure 1 *e*).

3.2 Jet-induced bubbles

It is known that, when cylindrical liquid jet plunges into a water surface, a wedge-shaped cavity is formed around the jet, and the tip of the cavity is fragmented into bubbles. We found that the surfactant effect works for reducing bubble size, compared with the distilled water, following the lognormal size distribution (see figure 1 *f* and *g*). The population of the jet-induced bubbles monotonically increases with the surfactant concentration. We also found the mean diameter, population and rise velocity of bubbles in surfactant water are identical with those in artificial seawater.

3.3 Residual foams

When rising bubbles come up on the free-surface, they may remain on the surface as residual foams. The population, size, rates of coalescence and collapse of the residual foams also highly depend on the surfactant concentration.

4. CONCLUSIONS

We observed the whole processes through a bubble lifetime, i.e. bubble formation, evolution and breakup, highly depend on the surfactant concentration, which indicates that heat, gas and momentum flux transported through oceanic aeration also depend on the concentration which varies with local oceanic biological activity.

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