Experimental study for bubble waves characteristically seen in Guinness

*Akane Kinoshita[1], Atsushi Toramaru[1]

1. Department of Earth and Planetary Sciences, Faculty of Sciences, Kyushu University

An analog experiment was performed to investigate the hydrodynamic behavior of a two-dimensional bubbly flow. Bubble waves, spatially periodic distribution of bubbles in bubbly flows, are sometimes observed in various natural situations. In particular, a pint of Guinness beer is a familiar and impressive example of bubble waves. The bubbles are distributed nearly uniformly at the moment when Guinness is poured in a pint glass, and a few seconds later, layers or waves of bubbles develop and propagate downward.Previous works studied the formation and development processes of these waves only theoretically. The present study provides experimental data for characteristics of bubble waves and examines the validity of mathematical models by previous works.
We conducted a series of analog experiments using water and the hollow glass particles (glass bubbles) as analog materials of a beer liquid and bubbles, respectively, presuming that the bubble waves in Guinness are caused by the relative motion between rigid spheres and liquid by buoyancy due to the density difference, but not by the formation and dissolution process of bubbles. We mixed the liquid and the glass bubbles in a rectangular container by gently shaking it. The bubble segregation or relative upward migration of bubbles starts from the homogeneous mixture as an initial state just after stopping shaking. We found that the bubble waves form during the upward segregation of bubbles under some conditions.In order to constrain factors governing the formation of bubble waves, we conducted the series of experiments with varying the volume fractions of the glass bubbles, sizes of them and the inclination of the container. We found that the bubble waves formed only when we incline the container, that is, with non-vertical side wall. If we set the container vertically, the bubble waves didn' t form. On the other hand, if we incline the container, we observed a bubble-free layer along the lower inclined wall where liquid flows downward. The wave like structure of the glass bubbles with the wave length about 7mm developed near the lower wall of the inclined container under certain conditions. We represent the condition for wave formation as a phase diagram which is a function of controlling parameters. It is important that the wave formation requires non-zero positive value of inclination, in such conditions a thin bubble-free layer near the lower wall develops.It is found that the wavy structures reached steady state after a certain period of time of transient state, and eventually the formation of waves stopped. The ratio of duration time of wave formation at steady state to total duration time is nearly constant regardless of controlling parameters. We analyzed the time development of waves and obtained wave velocity and frequency by image analysis for the movies. Waves propagated at constant velocity during a certain period of time after their formation, and slowed down before their disappearance near the bottom. They sometimes coalesced each other, unlike a solitary wave. The wave velocity at early 20s of steady state was constant at any conditions, and the wave frequency was proportional to the volume fraction of the glass bubbles. Our experimental results suggest that the bubble-free layer plays an important role in wave formation rather than the bubble nucleation and growth or diffusion, and that the wave formation can be described by the two-dimensional shallow water theory leading to the roll waves. We propose the formation mechanism of bubble waves by applying the linear stability analysis on the roll waves at the thin fluid film in an inclined channel to the bubble-free layer along the lower side wall.

Keywords: bubble wave, bubbly flow, periodic distribution of bubbles, two-dimensional flow, analog experiment

