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Behavior of Formation and Departure of Two-dimensional Bubbles

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Key Words: *Bubble dynamics, Two-dimensional bubble, Hele-Shaw cell, Bubble formation, Non-linear features*

1. Introduction

We employed two-dimensional bubbles as a model to explain the complicated boiling phenomena. Several measurements and their analyses on two-dimensional bubbles are presented in this paper. Although this two-dimensional isothermal system and three-dimensional boiling phenomena had different nature, the simplified two-dimensional model was efficient for understanding basic bubble behaviors.

We used Hele-Shaw cell, a narrow gap between two parallel plates, to form the two-dimensional bubbles.

Maxworthy [1] worked on rising motion of the two-dimensional bubbles. In previous paper [2], we researched on the coalescence of two-dimensional bubbles. In this paper, we focused on departing behavior of two-dimensional bubbles.

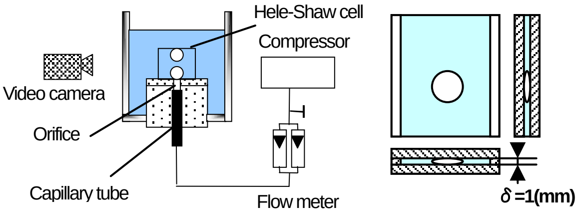

Fig.1 Experimental Apparatus

2. Apparatus and procedure

The experimental apparatus is shown in Fig.1. In the water pool, two plates were set parallel to form a Hele-Shaw cell. The experiment was carried out in the air-water isothermal system under atmospheric condition. The diameter of the orifice was 2mm. The parameter was the air volume flow rate, which was varied from Re=5 to Re=300. The surface of the two parallel plates was coated to be wet. A high-speed video camera was used to record the various bubble behaviors.

3. Results

3.1. Growth, detachment and rising motion The variation of bubble center with time in growth, detachment and rising is shown in Fig.2. The bubble center displacement shows the variety of the behavior. As the flow rate increased, it was likely for the bubble to affect the succeeding bubble. Two periods bifurcation (Re=30) and four periods bifurcation (Re=70) were observed.

3.2. Characteristics of detachment Figure 3 shows the relation between bubble volume and air flow rate. Here the bubble volume is normalized by using capillary length, and the

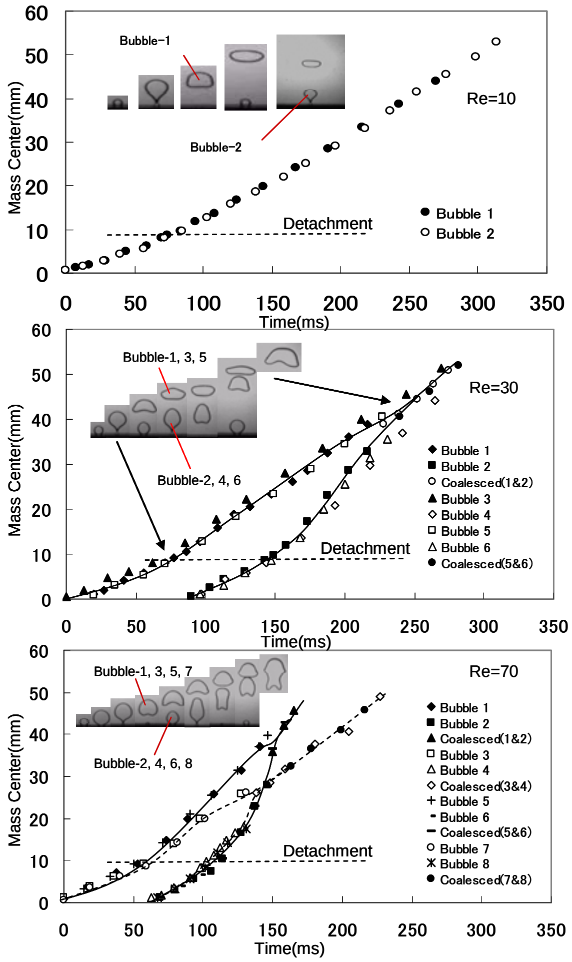

Fig.2 Displacement of bubble mass center

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air flow rate is represented by the orifice Reynolds number. In three-dimensional bubble, the bubble volume is constant at low flow rate, whereas the volume grows exponentially at high flow rate. It is known that the inertia force and surface tension are important at low flow rate, whereas the inertia force and buoyancy force are dominant at high flow rate. In contrast, two-dimensional bubble showed different characteristics. There was no constant-bubble-volume region. Surface tension is negligible except for the very low flow rate, say Re<5.

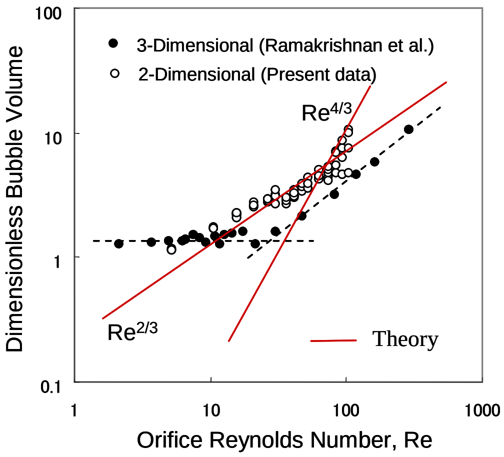


Fig.3 Bubble departure volume and its theoretical analysis

3.3. Analytical model of detachment Katto and Yokoya [3] theoretically derived the following relation for boiling bubble from the buoyancy-inertia balance:

$$V^* \propto Re^{6/5} \quad \text{(High flow rate:} \quad Re \geq 100\text{)}$$

As shown in the previous report [2], the authors applied this method to the two-dimensional bubble to obtain the following result:

$$V^* \propto Re^{4/3} \quad \text{(High flow rate:} \quad Re \geq 100\text{)}$$

Fig.4 shows the comparison between this analytical result and experiment results. It is clear that the agreement is good only at high orifice Reynolds number. If we suppose buoyancy-viscosity balance, we can obtain the following relation:

$$V^* \propto Re^{2/3} \quad \text{(Low flow rate:} \quad 100 > \text{Re)}$$

This result explains the bubble volume dependence on air flow rate fairly well at low flow rates.

3.4. Non-linear characteristics of detachment Fig.4 shows the detachment frequency together with the photography of the bubble aspects. Bubble did not always detach periodically. Namely, multiplicity (non-linearity) arose at high flow rate. In this experiment, detachment frequency became aperiodic when the flow rate was higher than Re=30. In high flow rate region (Re>100), chaotic features appeared. In these regions, it is difficult to distinguish successive generating bubbles.

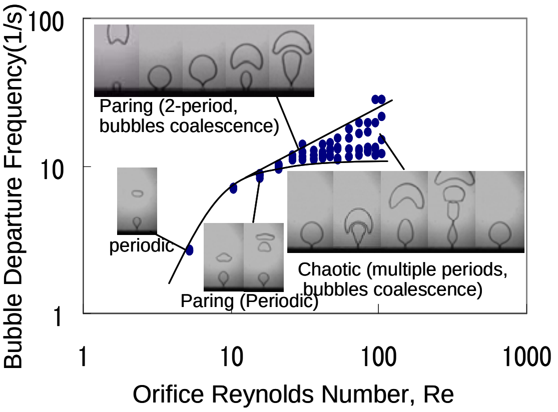
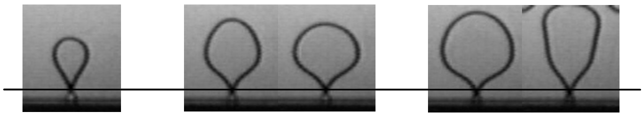


Fig.4 Multiciplicity of bubble departure frequency

3.5 Detachment Condition From the video movie (Fig.5 are some of the snapshots), it is found that the height of the neck of the detaching bubble was independent of the air flow volume rate. The height was always approximately 2mm. This value is almost the same to the three-dimensional case. Zhang and Shoji [4] [5] proposed a model basing on the Raleigh instability, while it may apply also to two-dimensional cases.



Re=10 Re=30 Re=70

Fig.5 Bubble detachment condition

4. Summary

Various features of two-dimensional bubbles were investigated experimentally and analytically. Further study for the effects of parameters such as orifice diameter, cell width and wall wet effect is required. More detailed analysis for bubble detachment should also be done in future.

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