Surfactant Effect on Bubble Motion in Rectangular Micro-channel with T-mixer

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1. Introduction

A micro-channel is a common component in various fields, for example, micro-channel heat sink, compact heat exchanger, and lap-on-a-chip [1]. In this study, we investigated the effects of surfactant on the bubble motion of nitrogen gas in a 510 μm × 470 μm rectangular micro-channel using a sodium dedecyl sulfate (SDS) surfactant. We selected different concentrations of SDS based on the surface tension of water (70 mN/m). The mole fraction of 1.9 mM and 3.71 mM show a surface tension of 60.29 mN/m and 50.62 mN/m, respectively. These will be expressed as Water 70, SDS 60 and SDS 50. More details including experimental facilities and procedure were described in Choi et al.'s previous work [2, 3].

2. Model and Results

2.1 Unit Cell Model

A unit cell model is a concept for bubble train flow, which is a periodically repeated flow pattern of a single bubble and liquid slug regimes as shown in Fig. 1(a). Another important parameter is the number of unit cells, because the number of unit cells is a magnification factor for an interesting period. In this study, we analyzed all phenomena including the pressure drop based on the unit cell model.

2.2 Bubble Shapes

In a micro-channel, a major flow pattern is an elongated bubble, which is a longer bubble than the length of a conventional plug due to a confinement effect of micro-channel. Fig. 2 shows the elongated bubble shape for a long bubble (a) and short bubble (b). The area covered by a thin film is increased as surface tension is reduced. In addition, this trend is clear in a tail region, which is the same as the results of Ratulowski and Chang [4]. They reported this film thickening phenomenon occurs only when the bubble length is larger than a critical value in a circular capillary.

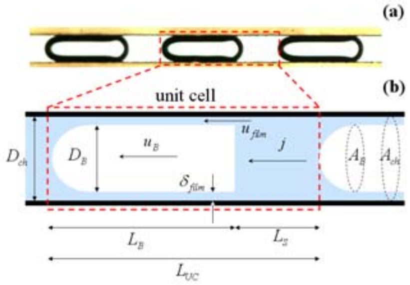

Fig. 1. Unit cell model: (a) visualized bubbles (b) conceptual image [3].

2.3 Bubble Velocity and Void Fraction

The bubble velocity is governed by the total and film velocities, and the areas of the film and bubble as shown in Fig. 1. As the area of the bubble decreased, the bubble velocity increased due to a conservation of volume flow rate. Therefore, the surfactant enhanced with an increase of the bubble velocity (Fig. 3), which is the same result of the visualization in section 2.2. Moreover, Fuerstman et al. reported that the flow through the corners reduced at a higher concentration of the surfactant [5]. If the corner flow slowed, the bubble

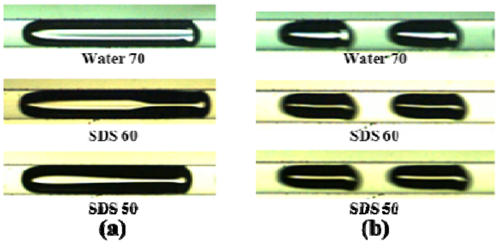

Fig. 2. Single bubble pattern (flow direction: left): (a) j_L = 0.13 m/s, j_G = 0.6 m/s, (b) j_L = 0.6 m/s, j_G = 0.6 m/s.

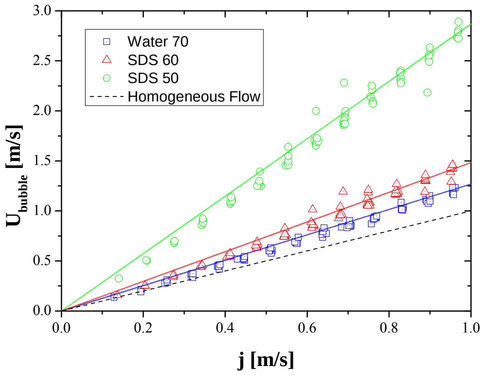

Fig. 3. Bubble velocities for water and SDS solutions

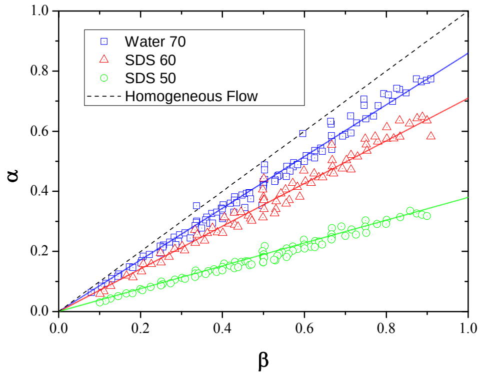

Fig. 4. Void faction(α) and volumetric quality(β) for water and SDS solutions

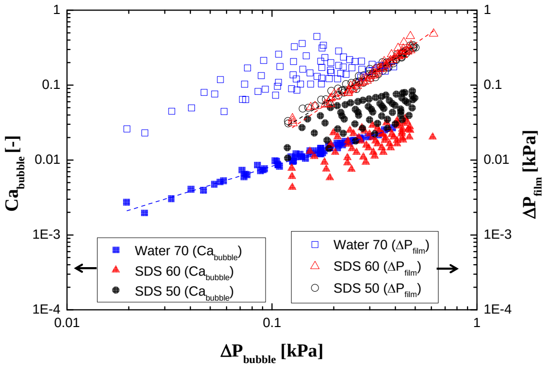

Fig. 5. Correlation of the pressure drops with Capillary number and the pressure drop in film region.

velocity increased. The amount of reduction of the flow in the film region should be taken over by the bubble region. The result of void fraction shows the same tendency of the bubble velocity. The higher void fraction means a smaller area occupied by the gas phase. Thus, the relation between slopes in Fig. 3 and Fig. 4 show an inverse of the coefficient [4].

2.4 Pressure Drop in Bubble Region

Generally, a pressure drop in the bubble train flow is classified with a pressure drops in the liquid slug, bubble body including thin film, and bubble nose-tail (Fig.1). Pressure drop models were reported; circular capillary [4, 6] and rectangular micro-channel [3]. The pressure drop in a liquid slug region is obviously the same as the pressure drop of a single phase. Therefore, the pressure drop in the bubble region including film and nose-tail are extracted with the pressure drop in the liquid slug region. Choi et al. reported that the pressure drop in the film region is negligible. They also proposed a new pressure drop correlation for the nose-tail region in a single bubble with the Capillary number [3]. However, their result is not satisfied with the case of a surfactant solution. They have a dependency of the length of the bubble and liquid flow rate. The pressure drop of the bubble region for water shows a correlation with the Capillary number, but that for surfactant solutions shows correlation with the pressure drop in the liquid film, as shown in Fig. 5. In conclusion, the pressure drops in the bubble region for water and surfactant solution are governed by the nose-tail region and the liquid film region, respectively.

3. Conclusions and Further Works

This study is an extension of previous work on the bubble behavior in a rectangular micro-channel. A surfactant (e.g. SDS) effect on the bubble behavior in a rectangular micro-channel was studied. The film thickness surrounding the bubble is increased in the surfactant solution. It makes the area of the bubble smaller. Therefore, the bubble velocity increased and the void fraction decreased. The pressure drop in the bubble region for a surfactant solution is higher than that for water. There are two contributive pressure drop components, i.e., a bubble nose-tail and liquid film including corner regions. For water, the pressure drop governed by the bubble nose-tail contributes to the pressure drop in the bubble region, but the pressure drop in the liquid film is negligible. For the surfactant solution, and vice versa, the pressure drop in the liquid film is a major pressure drop component. Apparently, the surfactant has an influence on bubble behavior. However, there is no clear physical understanding of this. Intensive work for different fluids will be conducted to understand physical reasoning and to propose universal correlations.

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