Interfacial Dynamics of Immiscible Liquid-Liquid Displacement and Breakup in a Capillary Tube

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Understanding interfacial dynamics and liquid film thickness in two immiscible fluids is important in two-phase flow research [1] because the interfacial area of fluid film and its thickness have a significant impact on the heat and mass transfer processes. However, the processes of liquid film formation, development and breakup are complex which involve the interfacial tension between fluid-fluid and fluid-solid, the heating process of fluid dynamics, the thermal effect and the capillary induced instability of thin liquid film breakup. As a consequence of the small length scale, the capillary forces play a fundamental role in the physics of the phenomena. For the high surface area and volume ratio will affects the evaporation of the film fluid. Previous researches show the relationship between liquid film thickness and the flow boiling heat transfer in microscale [2, 3]. Taylor [4] first gave the mean liquid film thickness remaining on the wall by measuring the difference between bubble velocity and the mean velocity.

Different methods to measure the thin film thickness based on different physical phenomena have been constantly proposed. Normally, these methods can be divided into 3 groups: acoustic methods, electrical methods and optical methods. Lu et al. [5] measured liquid film thickness of R113 and FC-72 inside a horizontal rectangular channel. By measuring the different arriving times of echo ultrasonic waves by different interfacial reflections, the film thickness can be calculated. Wang et al. [6] presented an analytical solution to estimate the film thickness in two-phase annular flow utilizing electrical resistance tomography. The resistances were measured after two electrodes were fixed to the pipe wall. Both the relationships between resistance and water film thickness for the concentric case and eccentric case were considered to determine the film thickness. Interference and pixel counting are two common optical methods. Ji and Qiu [7] presented an interference fringe film thickness measurement method by a 2D spatial fringe scattering technique. They utilized the relationship between film thickness and the spatial frequency of scattered fringes. Steinbrenner et al. [8] measured the thin film thickness in air-fluid two phase flow by counting the number of pixels after seeding fluorescence molecule into the water.

In this paper, an annular type thin water film formation, velocity field and breakup in a two immiscible fluid system in a capillary tube is presented as shown in Figure 1.

Fig. 1 Liquid film formation (a) Initial condition, (b) Film formation, (c) Film breakup
A novel method for measuring the interfacial liquid film thickness between immiscible liquids of annular oil liquid and a water slug/droplet (oil-water-oil) in a micropipe is proposed. A water plug/droplet was introduced into kerosene oil and pushed forward under a constant pressure. The interfacial film dynamics of oil-water interaction in a capillary tube is measured utilizing an improved method proposed previously. At the same time, by seeding particles in one liquid phase, the velocity field inside the film is measured by micro resolution particle image velocimetry (µPIV). The combination of film thickness measurement and inter velocity filed measurement can be utilized to analyze the theoretical explanation of the thin film generation in detail. Furthermore, a ripple pattern film thickness will be presented when a long annular water film is formed.

References