Contents lists available at SciVerse ScienceDirect

Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

Liquid flow pattern around Taylor bubbles in an etched rectangular microchannel

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ABSTRACT

Liquid flow around Taylor bubbles and the motion of bubble interface in a rectangular microchannel etched on a microfluidic chip were investigated using a three-dimensional particle tracking method. The Taylor bubbles were generated by releasing the dissolved air in working the liquid (water) through heating the microfluidic chip to 35–55 °C and had low velocities (15–1500 μm/s). Three-dimensional velocity distributions of liquid recirculation flows surrounding the Taylor bubble head and tail were obtained by tracking submicron fluorescent particles seeded in the working liquid and the motion of the bubble interface was analyzed by monitoring the motions of the particles attached on the bubble interface. The high velocity film flow through the microchannel corners acted as a liquid jet in front of bubble head and drainage into the corners behind the bubble tail to drive the liquid recirculation flows. The bubble interface near the microchannel corners was also moved by the strong liquid shear induced from the high velocity liquid flow in the microchannel corners. This high velocity liquid flow through the corners could be considered to be driven by the pressure drop over the Taylor bubble. The pressure drop resulted from the decrease of bubble surface mobility due to tracer surfactant in the gas–liquid interface.

Keywords: Taylor bubble; Slug flow; Microchannel; Three-dimensional tracking; Submicron particles; Diffraction pattern

1. Introduction

In the past decades, two-phase flows in small pipes have been a major research subject in the field due to their various applications. In particular, as the sizes of flow channels decrease to hundreds of microns, the slug flow regime dominates the gas–liquid two-phase flows in the microchannels and Taylor bubbles play an important role in determining the flow characteristics of the micro slug flows (Zhao and Middelberg, 2011). A Taylor bubble will dramatically change nearby liquid flow and therefore has significant effects on the key performance of some microfluidic devices such as micro gas–liquid reactors (Yue et al., 2009; Shao et al., 2010), micro bubble pumps (Song and Zhao, 2001), micro heat sinks for electronic cooling (Lee et al., 2005), and so on (Günther and Jensen, 2006; Gupta et al., 2010).

A number of early experimental and theoretical investigations indicated that liquid in slugs in front and back of a Taylor bubble has recirculation flows relative to the bubble in a capillary tube if the Capillary number, $Ca = \mu_l U_b/\sigma$, where μ_l, U_b, and σ are liquid viscosity, bubble velocity and interfacial tension, is small (Taylor, 1961; Thulasidas et al., 1997). Numerical simulations and micro-PIV experiments of liquid flows around Taylor bubbles in capillary tubes (Taha and Cui, 2004; Günther et al., 2004; Gupta et al., 2009; King et al., 2007; Yamaguchi et al., 2009) showed that the recirculation flows are generated by interactions between the fast moving bubble and slow liquid flow near the tube wall and, as Ca decreases, a Taylor bubble will occupy more the tube cross section and the recirculation zone will become larger since the thickness, δ, of film surrounding the bubble decreases as $\delta/D \sim Ca^{2/3}$, where D is the capillary diameter (Bretherton, 1961; Aussilous and Quéré, 2000; Akbar and Ghiaasiaan, 2006). As a result, the Taylor bubble acts as a piston with almost the same diameter of the tube to push the liquid slug forward and its velocity relative to the liquid slug approaches zero in a similar way of the film thickness.

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Received 3 July 2011; Received in revised form 31 October 2011; Accepted 6 November 2011
0263-8762/$ – see front matter
doi:10.1016/j.cherd.2011.11.008