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Dependence of micro-drop generation performance on dispenser geometry

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ABSTRACT

In this paper, the drop generation performance, represented by the speed of generation and the attainable size range of drops, of λ-junction type micro (∼100 μm) dispensers was examined for various heights, widths and fluid injection angles quantitatively. Target range of drops was about the same size of the channel hydraulic diameter (0.8–1.2 $D_{h,c}$) that is known to be most efficient for internal mixing of different components within micro-drops. Viscosities of the disperse and continuous phases were 2.7 and 2.3 mPa s, respectively. Also, the superficial velocity range of the disperse phase was 0.002–0.128 m/s and that of the continuous phase was 0.02–0.15 m/s. Hence, the corresponding ranges of the capillary and the Reynolds numbers (based on the channel width) of the continuous phase were 0.004–0.034 and 1–32, respectively. Within the present test ranges, the drop generation performance was improved with the smaller width ratio (between the side and the main inlets), and at the aspect ratio of about 0.8 and the injection angle of about 120°. Furthermore, through the detailed observations, the geometrical similarity of the bulged part of the disperse phase was confirmed to exist between the cases with different junction dimensions (widths and height), which is an important clue for prediction of drop sizes.

1. Introduction

In lab-on-a-chip systems, there is a difficulty in mixing different liquids because they are generally in laminar conditions. To overcome this difficulty, the technique of internal mixing within liquid drops has recently received attention [1–7]. Two different liquids are introduced to form drops (disperse phase) surrounded by the immiscible carrier liquid (continuous phase) moving with a higher velocity. Then the two components within the drops are rapidly mixed with each other by the internal circulation (induced by the interfacial shear between the drop and the carrier liquid). Mixing within a liquid drop has several advantages over other mixing techniques: reduction of channel blockage by precipitates, management of parallel reactions, and maximization of reaction performance with low consumption of the carrier liquid [1].

The primary factors influencing the mixing efficiency in a drop are the initial arrangement of the components and the drop size [1–3]. Tice et al. [2] reported that the components should be initially positioned horizontally (as in Fig. 1a) than vertically (Fig. 1b) to enhance mixing by utilizing the axi-symmetric nature of the internal flow. Thus, Song et al. [1] attempted to reduce the influence of initial arrangement at the inlet by proposing a serpentine-type microchannel (Fig. 2) that agitates the axi-symmetric internal circulation within the drop. Similarly, loss of internal circulation symmetry is observed by Günther et al. [4] also for the gas–liquid flows. Regarding this, Muradoglu and Stone [3] have searched the conditions to maximize the mixing performance in a serpentine microchannel through a numerical simulation. They reported that the best mixing performance could be achieved when the drops have their size comparable to that of the channel, that is, within the range of 0.8–1.2 $D_{h,c}$. Furthermore, Tanthapanichakoon et al. [5] have studied on the phenomena of mixing by internal circulation with the slug cross-sectional shape (two-dimensional or three-dimensional shape), slug height/diameter and length, slug velocity and initial arrangement of reactants inside the slug taken as the simulation parameters. To cover a wide range of micro-fluidic applications, they conducted their simulation for liquid slugs of 50–250 μm in height (for two-dimensional shapes) or 50 μm in diameter (for three-dimensional shapes) and the length-to-height (or length-to-diameter) ratios of 0.5–10. As a result, they proposed a modified Peclet number $\left(\mathrm{Pe}^* = u_{slug} r_{slug}^2 / L_{slug} k\right)$ that reflects the effect of the slug size (length and height or diameter) as a dimensionless parameter to control the reaction rate. In summary, the drop size plays an important role in mixing within the drops and generation of drops with proper sizes (D_{drop} = 0.8–1.2 $D_{h,c}$) turns out to be very important.

There are several methods for generation of micro-drops; the co-flow method, flow focusing method and the cross-flow method. Among them, the crossflow method is the most widely used because of its easy fabrication and simple structure [6,8–19]. Fig. 3a shows a schematic view of the crossflow method using a λ-junction. The disperse phase is injected into the side inlet to form

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