



Emission of liquid droplets from an interface of bidrops pulled by a ferrofluid in a microchannel

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ABSTRACT

In various microfluidic devices, controlling the flow rate of liquid or gas accurately at micro or nanoliter volume levels is required. By using a ferrofluid, the flow of a liquid or gas in a microchannel can be controlled by the driving power exerted on the ferrofluid. In our previous study, an unsteady flow of a liquid slug caused by the driving force from the ferrofluid was investigated in a 200 μm circular microchannel. In the present study, combinations of various liquids with the ferrofluid were examined in two microchannels (130 μm and 200 μm diameter). The relationship between the emission of liquid droplets and interfacial deformation of the bidrops was investigated experimentally and analytically. The emission of liquid droplets from the deforming interface of the bidrop was studied for liquids of different viscosities. The interface shape was observed to change continuously until a liquid droplet was emitted from the interface of the immiscible liquids. When the ferrofluid velocity was increased, necking of the liquid–liquid interface occurred and some liquid droplets were emitted from the interface. The mechanism of liquid droplet emission following the interfacial deformation was characterized, and a correlation was developed for the emitted droplet velocity in terms of Capillary, Reynolds and Weber numbers.

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1. Introduction

The field of microfluidics is rapidly developing with advances in biotechnology and $\mu\text{-TAS}$ technologies [1]. In various microfluidic devices [2], controlling the flow rate of liquid or gas accurately at micro or nanoliter volume levels is required. Recently, the motion of a fluid without external forces in a small tube has been studied focusing on self-propelling liquid slug motions [3]. In that study, various cases in which the liquid slug moved in the absence of gravity or a pressure force were introduced, and a train of juxtaposed liquid drops in a tube was found to move spontaneously, because of their asymmetry.

By using a ferrofluid, the flow of a liquid or gas in a microchannel can be controlled by the driving power exerted on the ferrofluid. In our previous study, an unsteady flow of a liquid slug caused by the driving force exerted by the ferrofluid was investigated in a 200 μm circular microchannel [4]. The velocity of the ferrofluid was found to vary with the dynamic contact angle of the liquid slug, which in turn depended on the liquid [5]. In addition, the surface tension and

kinematic viscosity of the liquid significantly affected the movement of the liquid slug. Therefore, the velocity of the ferrofluid was affected by the physical properties of the liquids being pulled. By visualizing the interfacial behavior of the bidrops, we could study the characteristics of fluid transport phenomena from the liquid–liquid interfaces in the microchannel. At sufficiently high velocities of the ferrofluid, emission of a liquid droplet from the liquid–liquid interface was observed [6].

In the present work, combinations of various liquids with the ferrofluid have been used in two microchannels (130 μm and 200 μm inner diameter) to investigate the relationship between the emission of liquid droplets and interfacial deformation of the bidrops experimentally and analytically.

2. Experimental apparatus and procedure

Fig. 1 shows the experimental apparatus used in this work. The motion of bidrops was studied in two circular microchannels (130 μm and 200 μm diameter) made of glass under the influence of an external magnetic field, which was produced by an electromagnet. The electromagnet was moved on a translation stage and the liquid flow inside the microchannel was observed using a CCD camera or high speed video camera. Many images were recorded

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