Numerical Study of the Controlled Droplet Breakup By Static Electric Fields Inside a Microfluidic Flow-focusing Device

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Abstract

Droplet-based microfluidics has received extensive research interests due to its superior control over the fluid flow [1]. Conventional passive microfluidic flow-focusing devices confront difficulties in controlling droplet sizes in dripping regime especially when the dispersed phase has a large viscosity [2]. It has been reported that external electric field can be used to manipulate the droplet breakup [3]. In the present study, a computational fluid dynamics (CFD) based level-set method coupled with perfect dielectric model has been applied to investigate the formation of viscous droplets inside water of sufficient low conductivity.

The two-phase flow, level-set in the Fluid Flow Module coupled with electrostatics in the AC/DC Module of COMSOL Multiphysics® are used in this study. The simulations are carried out in a conventional microfluidic flow-focusing device as shown in Figure 1. A typical computational domain consists of approximately 13,000 elements. The continuous phase which is modeled as water, is injected from the side two channels while the dispersed phase of high viscosity, which is modeled as silicone oil, is injected from the center inlet. One inlet of the continuous phase is connected to an external electric power supply while the other is connected to the ground. Due to the difference between the electric properties between the two phases, polarization charges are accumulated on the interface between the two phases.

As shown in Figure 2, the interaction between the electric field and the polarizations charges results in an electric stress that help to squeeze the dispersed phase. This effect is especially beneficial in those circumstances that hydrodynamic force could not decrease the droplet-size efficiently due to the large viscosity of the dispersed phase. The breakup process exhibits different behaviors when the electric fields of various strengths are applied due to the interaction of hydrodynamics and electrodynamics. As shown in Figure 3, the curve indicating droplet sizes versus the applied voltages linearly decreases if low voltage is applied. The curve crosses a transition zone where droplet size increases with the applied voltages. If very high voltage is applied, the droplet size decreases with the applied voltage again. The corresponding droplet breakup processes at different voltages are shown in Figure 4. The droplet breakup process is complicated due to the interactions between the governing forces, i.e., viscous force, inertial force and electrostatic force. The numerical simulation can provide insightful analysis for the

breakup process. The detail discussion of the results will be provided in the extended abstract.

Reference

1. A. Gunther; K. F. Jensen, Multiphase microfluidics: from flow characteristics to chemical and materials synthesis. Lab on a Chip 2006, 6
2. Z. H. Nie; M. S. Seo; et al., Emulsification in a microfluidic flow-focusing device: effect of the viscosities of the liquids. Microfluid. Nanofluid. 2008, 5 (5), 585-594.
3. D. R Link; E. Grasland-Mongrain; et al., Electric control of droplets in microfluidic devices. Angew. Chem.-Int. Edit. 2006, 45 (16), 2556-2560.

Figures used in the abstract

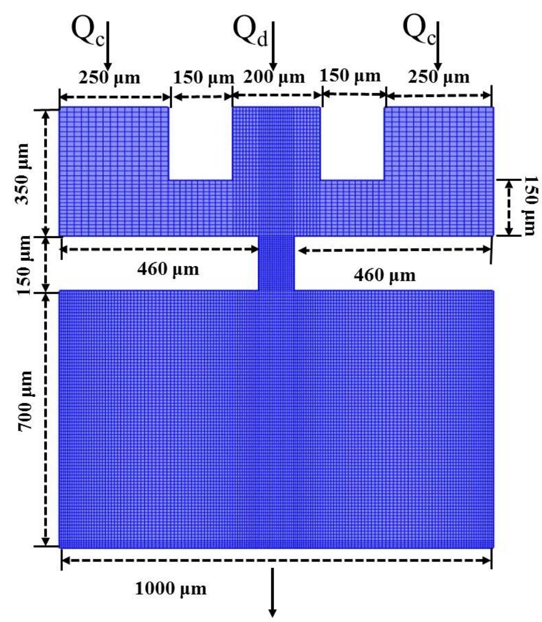

Figure 1: Geometry dimensions of the MFFD and the mesh used for this study. The dimensions of the orifice are: w_or=80 µm and L=150 µm, and it is placed at a distance of 150 µm to the upstream channels. The microfluidic channels have a uniform depth as 86 µm.

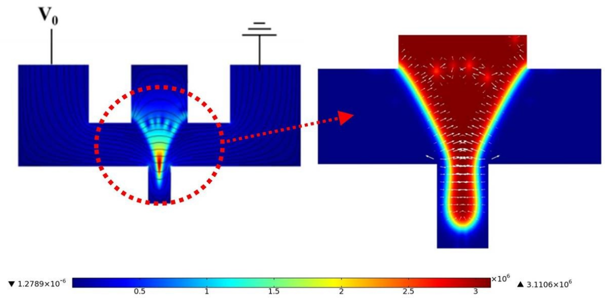

Figure 2: Contour plot of the electric field strength during the droplet formation at μd=50 cp, Qi =25 mL/h and Qo/Qi=50. The electric field lines are shown as the black lines. A high potential V0=240 V is applied on the left inlet channel of the continuous phase while the right channel is connected to the ground. The color map indicates the magnitude of the electric field strength. The right figure indicates the phase plot zoomed in the focusing region at the same time. The white arrows indicate the vectors of the induced electric force by the electric field.

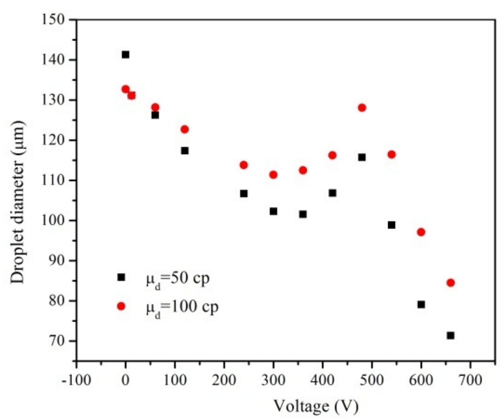

Figure 3: Droplet size and formation period a function of applied voltages at Qi =25 mL/h and Qo/Qi=50.

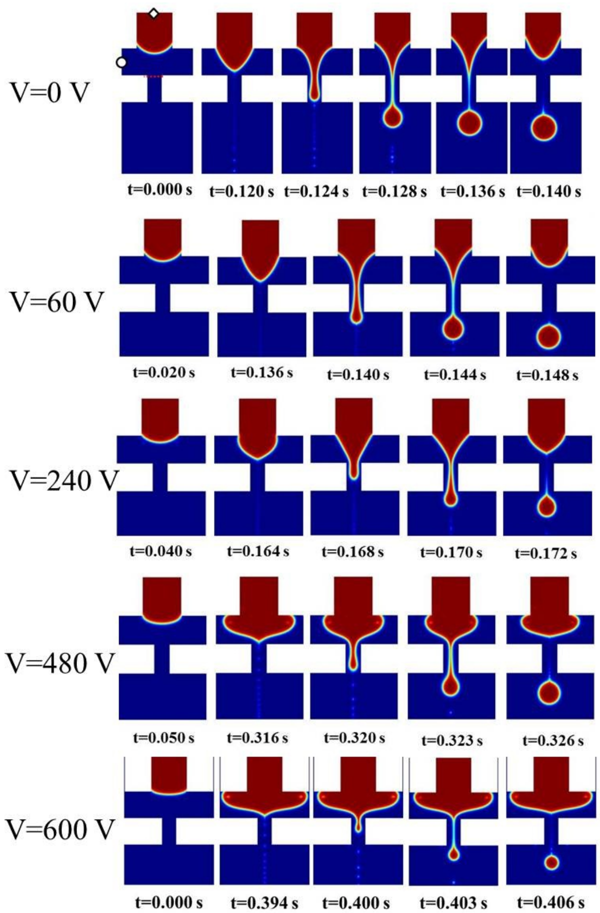

Figure 4: Droplet breakup process at different applied voltages.