Optimized Channel Geometry of a Flow-Focusing Droplet Generator for Parallelization

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Abstract

Microfluidic droplet generators are devices that can produce monodisperse emulsions of two immiscible fluids when shearing forces of a continuous phase overcome the surface tension of the disperse phase. Thus droplets are formed. Applications of this technology are found in high added value industries such as those in pharmaceuticals, photonics, aggressive chemical industry, molecular biology, and cosmetics.[1]

Wang et al. have summarized droplet generators with various geometries and characteristics[2]. Size of the droplets in microfluidic devices depends on several parameters such as: The dynamic behavior relative to the flowing rates, intrinsic properties or the fluids (viscosities and interface tension) and parameters correspondent to the geometry of the device. A common flow focusing device consists of a cross shaped constriction that focuses the disperse phase into a long thread prior to droplet formation. Due to this characteristic, it is possible to generate droplets with different sizes.

The COMSOL Multiphysics® Laminar Two-Phase Flow, Phase Field interface was used to model the flow-focusing device in three and two dimensional spaces and a comparison between the two is made. This module can easily couple the phase field model equation[3] with our problem for proper interface tracking

For all these simulations, only half of the device was drawn to simplify the number of nodes and operations by using the symmetry boundary condition. The simulations were executed with a wetted wall condition using a contact angle of $3\pi/4$. This parameter was measured using a KRUSS DSA100W drop shape analysis system for water and Polymethyl methacrylate (PMMA) surrounded by light mineral oil (Figure 1).

We have successfully simulated a flow focusing droplet generator in a two dimensional space which has given us information about expected flow rates and boundary conditions for a more complex simulation in a three dimensional environment. (Figure 2) shows the 2D simulation results where the droplets are generated.

The droplet size and size distribution of our device will be studied at different constriction/ channel geometries (i.e. square, rectangular and triangular cross-sectional areas for the cross-shape) and at the same flow rates. This will aid in optimizing the dimensions and shape of the

generator. Moreover, by simulating in a three dimensional space, we will also learn about the effect of a height difference (deeper channel) at the exit of the constriction in the dynamics of the system. (Figure 3)

Finally, using the post processing tools, we had been able to create graphics with information about the volume fraction of water in oil, streamlines of flow, and velocity magnitude. In addition, by using the integral operator we can precisely evaluate the size of the droplets. Using this model we will grasp a better understanding of the system and design a droplet generator with low dynamic range for parallelization.

Reference

[1] G. M. Whitesides, “The origins and the future of microfluidics,” Nature, vol. 442, no. 7101, pp. 368–373, Jul. 2006.
[2] J.-T. Wang, J. Wang, and J.-J. Han, “Fabrication of Advanced Particles and Particle-Based Materials Assisted by Droplet-Based Microfluidics,” Small, vol. 7, no. 13, pp. 1728–1754, May 2011.
[3] Y. Sun and C. Beckermann, “Sharp interface tracking using the phase-field equation,” Journal of Computational Physics, vol. 220, no. 2, pp. 626–653, Jan. 2007.

Figures used in the abstract

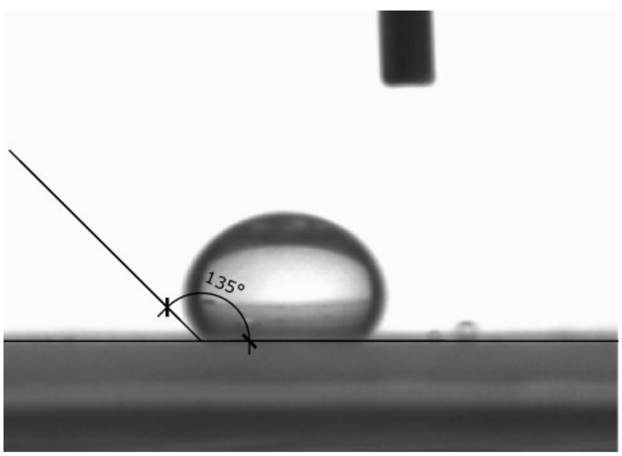

Figure 1: Contact angle measurement of water on PMMA surrounded by oil

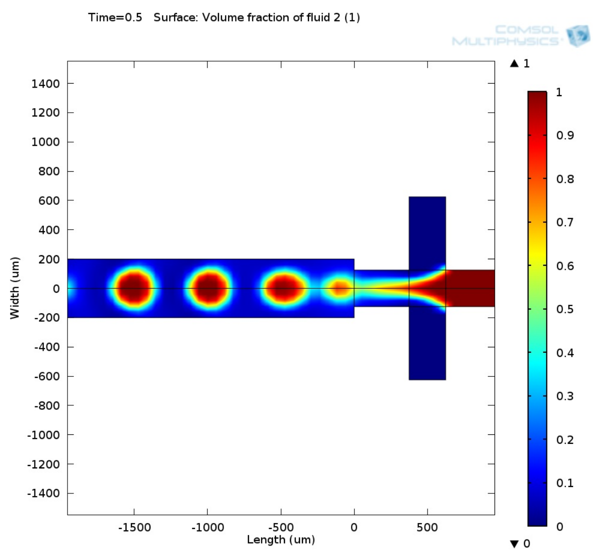

Figure 2: 2D simulation of the flow-focusing device

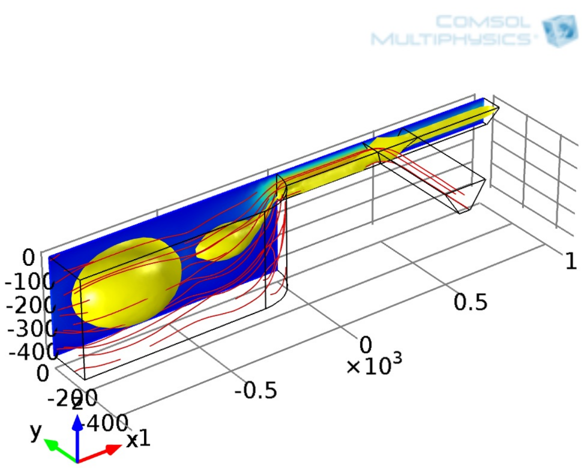

Figure 3: 3D simulation of the flow-focusing device