Simulation of a 3D Flow-Focusing Capillary-Based Droplet Generator

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Abstract

Introduction
Droplet-based microfluidics is a research area that has caught the attention of different disciplines in the past decade[1]. Droplets of immiscible fluids (typically water in oil W/O or oil in water O/W) have been used as confined pL-nL size reaction chambers in which reagents and conditions are precisely controlled. Applications of this technology include: single cell assays, gas-liquid reactions, point of care diagnostic devices, and synthesis of diverse materials such as: biomolecules, crystals, polymeric particles and nanoparticles. [1]-[3]

Different microfluidic droplet generators have been introduced to produce monodisperse droplets, however their fabrication is challenging and their characterization is time consuming, thus a model that can aid in their design is needed.

Use of COMSOL Multiphysics®
In this work we will be using COMSOL Multiphysics® to characterize the performance of a 3D flow-focusing microfluidic droplet generator in which the disperse phase (inner fluid) is hydrodynamically flow focused (in a 3D-space) by an immiscible continuous fluid, when both are forced to pass through a narrow orifice. The disperse phase then experiences elongation and finally droplet break up downstream.

These types of flow-focusing systems are usually manufactured by manually assembling tapered capillaries on a square channel [3]. Their fabrication process is laborious because of the alignment step. Therefore, virtual testing is much faster than doing design iterations and running the fabrication process.

Capillary based droplet generators offer a great control over the droplet generation. Other benefits include their improved droplet-size dynamic range, their reduced probability of clogging or fouling and their increased reliability compared to other types of droplet generators.

In COMSOL Multiphysics® we made use of the Phase Field Method [4] to study the interfacial motion of the multiphase flow. It allows us to see the geometric evolution with an Eularian formulation. We have been able to simplify the complexity of the system by running a 2D flow-focusing device and then revolve the solution along the axis of symmetry. This technique allows for a rapid convergence and shows promising results.

Reference

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[4] 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

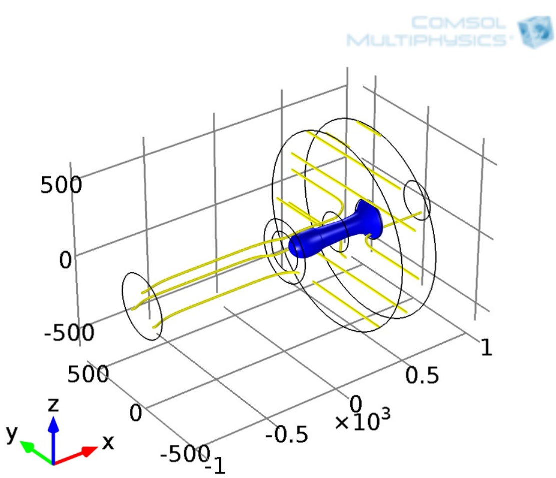

Figure 1: Capillary based flow focusing device (Time step 1)

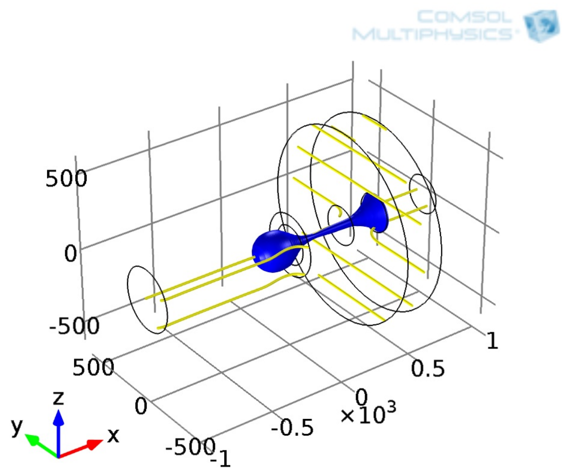

Figure 2: Capillary based flow focusing device (Time step 2)

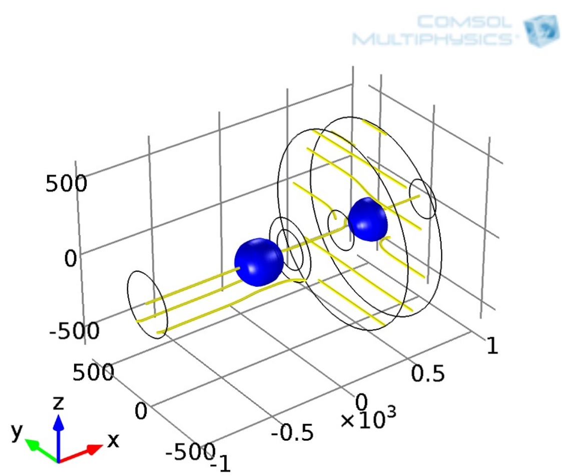

Figure 3: Capillary based flow focusing device (Time step 3)