Simulation of a 3D Flow-Focusing Droplet Generator

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Introduction

Nowadays, droplet microfluidics is a continuously growing topic because it offers a completely new horizon for assays in the Pico-liter to Nano-liter size where miniaturization challenges such as: fluids evaporation, liquid handling, molecule adsorption and absorption had been an obstacle to further scale down scientific experiments [1].

This project presents the multiphase 2D axisymmetric simulation of a three-dimensional flow-focusing microfluidic droplet generator using the laminar two phase flow, phase field module in COMSOL Multiphysics®. The performance of the device is characterized at different flow conditions. The generation frequency of droplets was also studied and shows direct correlation with the flow rates.

Model Design

The microfluidic droplet generator shown in Figure 1, consists of a standard glass capillary tube with inner diameter of 508µm that has a tapered reduction in diameter to form a 250µm orifice over a 375µm distance.

The device has an axisymmetric input for the disperse phase and a ring-like input for the continuous phase.
The ring-like emulates the entrance of the continuous phase from an outer channel. The height of this ring is 500µm and represents the thickness of the capillary tube.

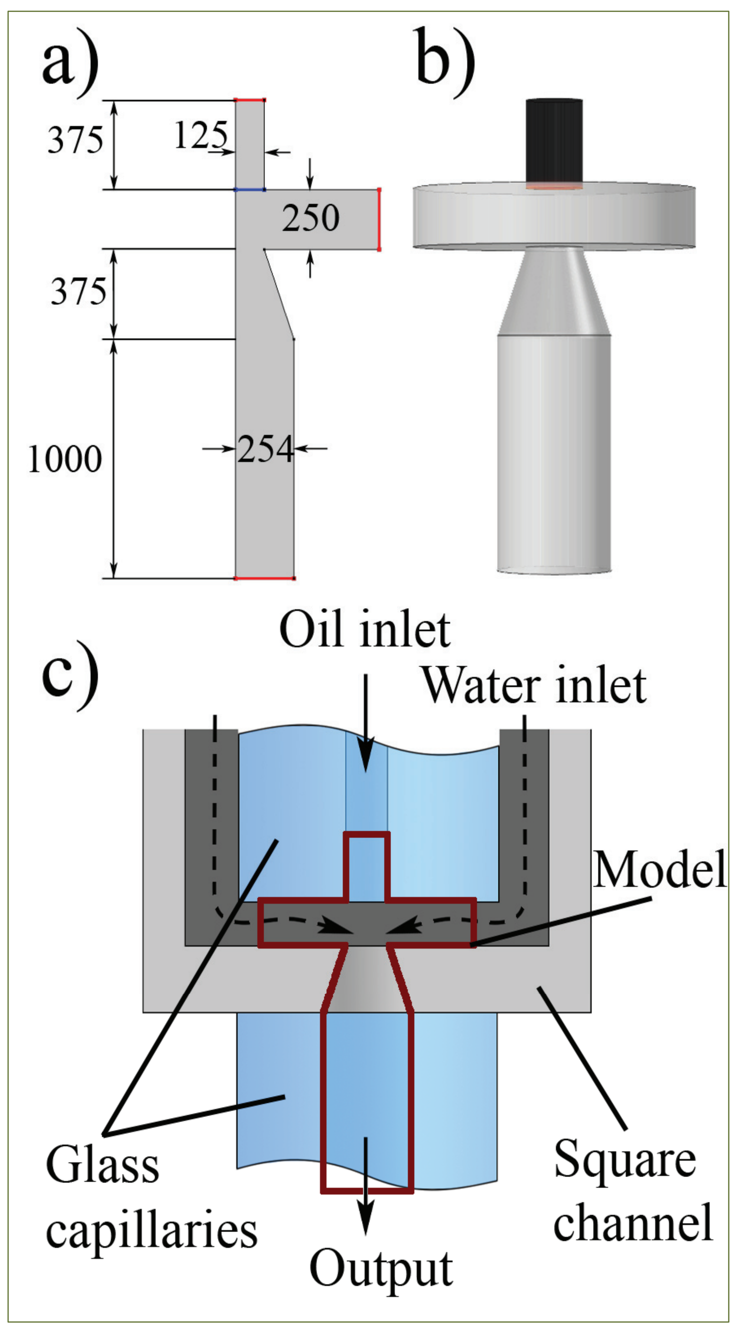

Figure 1. Diagram of the capillary-based microfluidic droplet generator. a) Top view 2D axisymmetric slice with dimensions. b) Solid of revolution formed by revolving the slice shown in a). c) Assembly schematic of the constriction of a capillary-based MFDG from which our model was derived.

Property	Oil (DP)	Water (CP)
Density (Kg/m^3)	1000	1000
Dynamic viscosity (mPa·s)	6.71	1.95

Table 1. Properties of Materials used in Simulations

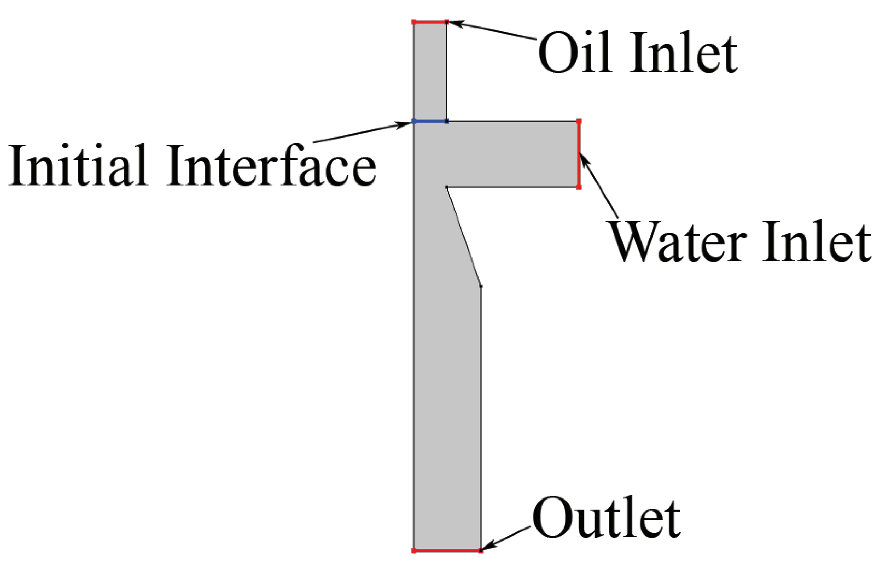

Figure 2. Boundary Conditions defined for the microfluidic droplet generator in the 2D axisymmetric model. The device has two inlets set with a constant flow rate. The outlet is set to have zero pressure with no viscous stress.

Simulation Results

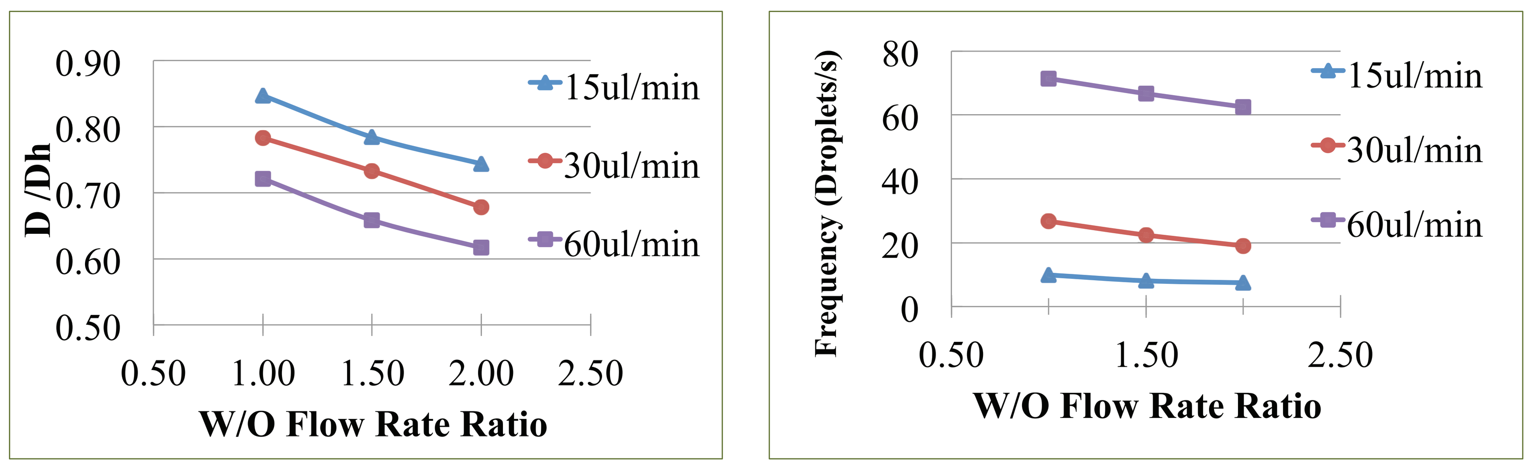

Figure 3. a) Normalized droplet size vs. Water/Oil Flow Ratio plot b) Frequency of droplet generation vs. Water/Oil Flow Ratios plot.

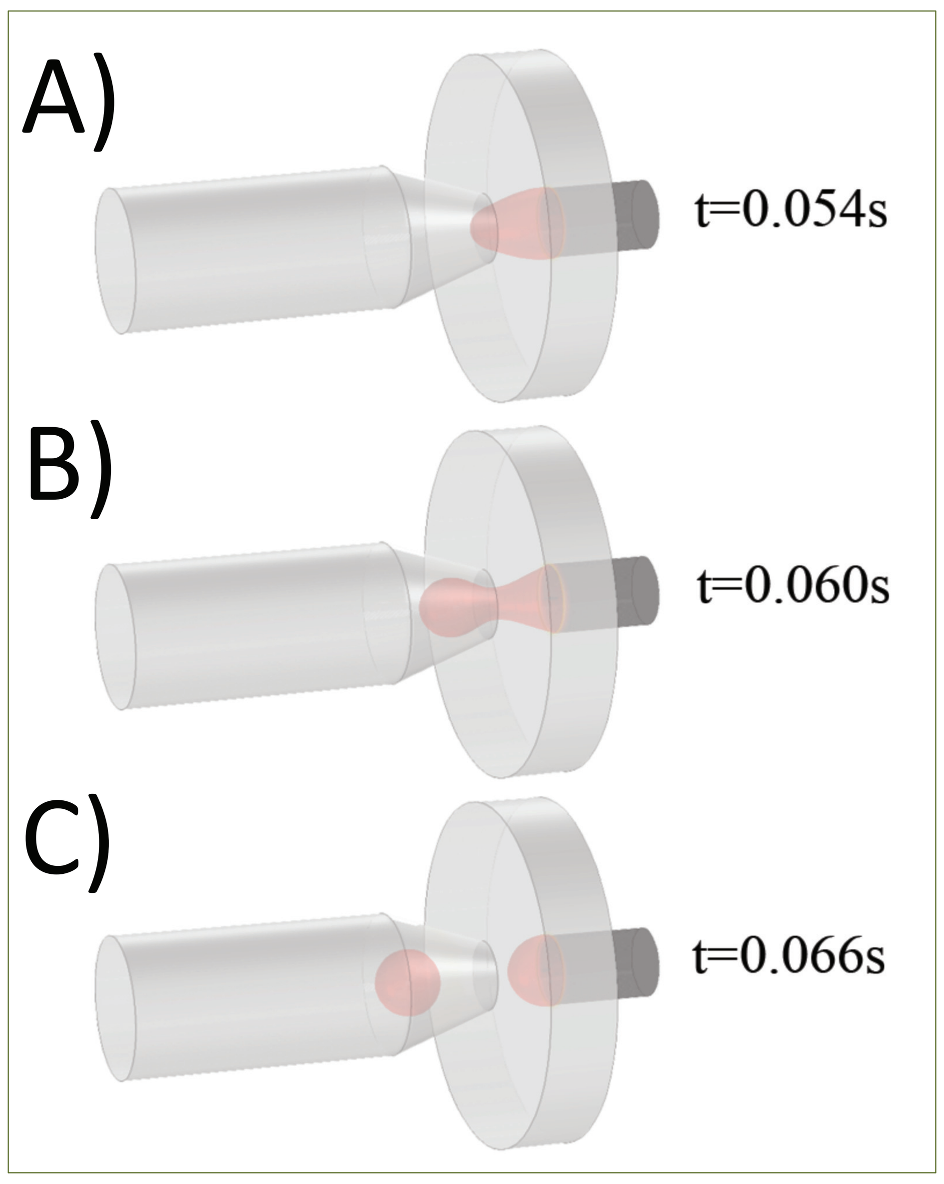

Figure 4. Typical time sequence for droplet generation at 15ul/min for both inlets, A) The DP meets the CP at the initial interface, B) Necking occurs by the focusing force of CP, and C) Droplet breakup.

Conclusions

In this work we have successfully simulated a capillary-based micro fluidic droplet generator. We took advantage of the device's axisymmetric geometry to model it in a simpler 2D fashion, which reduces the solution time significantly (less than 15 minutes). At small time increments in the time dependent study, it is possible to visualize the focusing behavior of the fluids during droplet formation. A correlation was found between flow conditions, and droplet diameter and frequency of generation. At higher flow rates, droplet diameter decreases, and frequency of generation increases.

References

1. D. N. Breslauer, P. J. Lee, and L. P. Lee, "Microfluidics-based systems biology - Molecular BioSystems (RSC Publishing)," *Molecular Biosystems*, 2006.

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