Simulation of a Symmetric and Parallelizable Constant-Volume Droplet Generator

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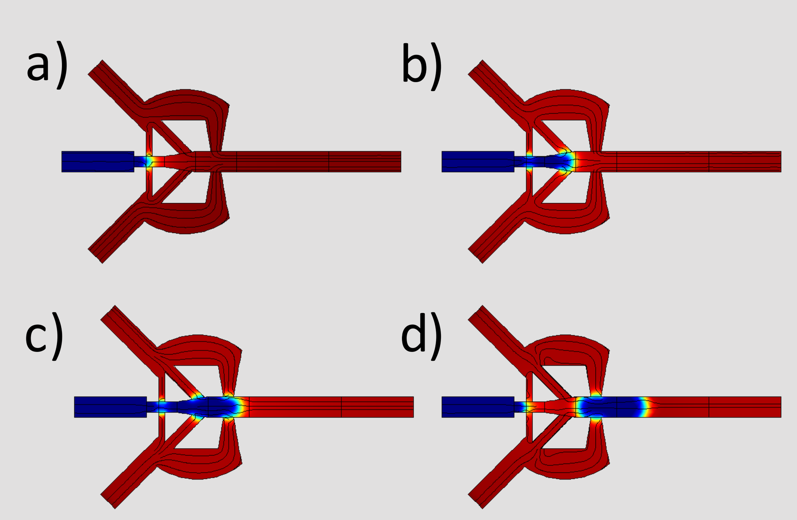
Introduction

Droplet microfluidics allows higher degree of control for biological assays and chemical reactions than any other method.
-However, their production is limited to small quantities (<10ml/h).
-Scale-up can be achieved through parallelization. Unfortunately, this is challenging due to crosstalk, and complex fluid mechanics interactions.



a) Initial Condition
b) Growth
c) Block
d) Break-up

Figure 1. Droplet Break-up Sequence

Computational Methods

We use the computational fluid dynamics (CFD) to simulate the laminar two-phase flow using the phase field method. A continuous phase field variable describes and tracks the interphase between both immiscible fluids in a time dependent study.

$Navier-Stockes$

$$\rho\frac{\partial \mathbf{u}}{\partial t}+\rho\left(\mathbf{u}\cdot\nabla\right)\mathbf{u}+\nabla p-\nabla\cdot\eta\left(\nabla\mathbf{u}+\left(\nabla\mathbf{u}\right)^T\right)=0$$

$Continuity-Equation$

$$\nabla\cdot\mathbf{u}=0$$

The simulated device is a modification of a classic flow-focusing generator. However, the droplet break-up mechanism is determine by the bypass system.

The target for droplet size is designed by the dimensions of the cavity.

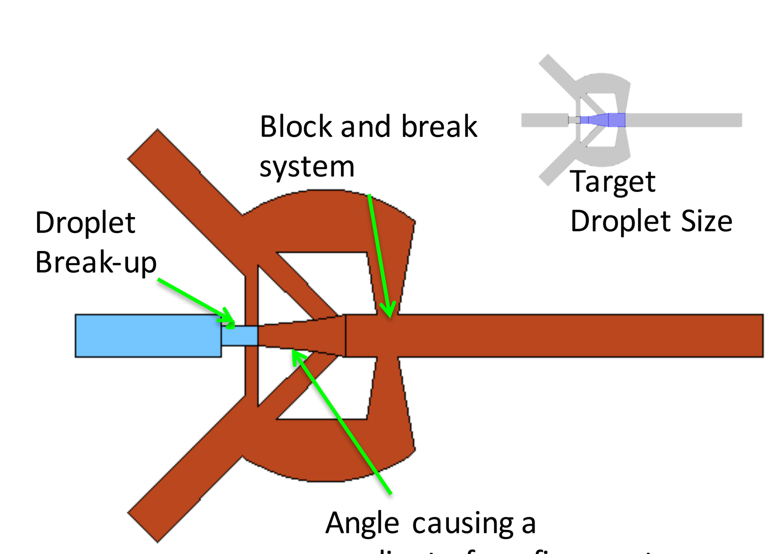


Figure 2. Symmetrical Constant Volume Generator

Results

Common microfluidic droplet generators, especially those known as flow-focusing generator, are very sensitive to the flowing rates. The simulation was run at several total flow rates and different oil and water flow rate ratios. The volume of the produced droplets remains constant for a wide range of flow conditions

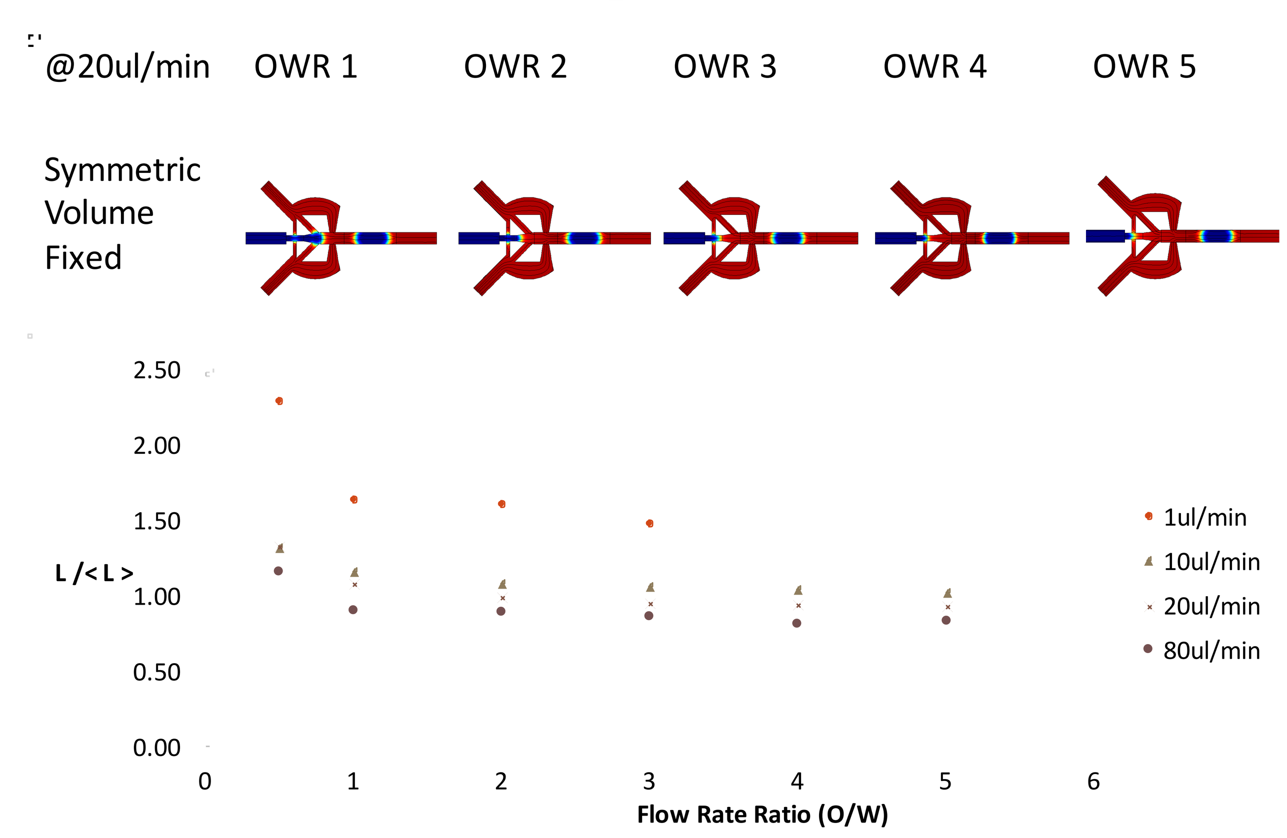


Figure 3. Consistent Droplet Formation

Our simulation also matches the behavior of devices fabricated using soft-lithography
Droplets of larger size were observed at very low total flow rates. At very high flow rates and low oil/water ratios, laminar flow was observed.

Table 1. Parameters and liquid properties

Parameter	Value
Oil Density (ρ_o)	$750 Kg/m^3$
Water Density (ρ_w)	$1000 Kg/m^3$
Oil Dynamic Viscosity (μ_o)	$1.34 mPa\cdot s$
Water Dynamic Viscosity (μ_w)	$1 mPa\cdot s$
Contact Angle (θ)	$3\pi/4 rad$
Interfacial Tension (σ)	$5\times10^{-3}\ N/m$

Conclusions: This symmetrical generator showed consistent and uniform droplet formation at different flow rates. The symmetry associated with this geometry is likely to reduce undesirable wettability problem that may lead to failure.

References

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