A Preliminary Design Of A Hydrodynamic Microtrap For Capturing Aqueous Droplets In Oil Media

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Abstract

Droplet-based microfluidic systems are emerging as an ideal platform for the high-throughput screening of eukaryotic cells aimed to understand the complex, multidimensional, and dynamic biological processes [1]. Here, aqueous droplets - containing the eukaryotic cells - suspended in oil media become captured in an embedded array of hydrodynamic microtraps for conducting a range of studies such as protein crystallization evaluation, cell apoptosis, and synthetic lethality tests [2].

In this work, through extensive COMSOL Multiphysics® simulations, we conducted a parametric study to analyze the effect of fluid (heptane oil/water) surface tension γ and the oil speed U on the aqueous droplet behavior in the hydrodynamic microtraps (Fig. 1). Specifically, the parametric study ranged over two orders of magnitude on the surface tension, γ ϵ (0.002-0.5) N/m and oil speed, U ϵ (0.005-0.5) m/s. This study resulted in the generation of a preliminary design chart - a plot of the droplet fate (trapped, merged, or dislodged) vs capillary number Ca - for the hydrodynamic microtraps. Our microfluidic system comprises of two aqueous droplets suspended in oil media and a channel bifurcation with two daughter channels - a microtrap and a bypass (Fig. 1a, b). To study and track the progression of the droplet behavior, at and beyond the channel bifurcation, we utilized the COMSOL® Microfluidics Module, modeled the system as a two-phase flow, employed the level-set method, implemented extra fine mesh, and assumed a hydrophobic channel wall (contact angle is 180°, [3]) (Fig. 1b, c).

Two important observations are reported: (1) For successful trapping of a droplet in the microtrap, the magnitude of the fluid (oil/water) surface tension γ and the oil speed U should be on the same order of magnitude (Fig. 1d). (2) For a low Ca, < O(10)-4, the droplets gets merged at the bifurcation - an undesired outcome; a medium Ca, O(10)-3, one droplet gets captured in the microtrap and the approaching droplet gets bypassed downstream - a desired outcome; and a high Ca, > O(10)-3, the captured droplet gets dislodged from the microtrap - an undesired outcome (Fig. 1e). These observations are in good agreement with the existing literature [2, 4].

Reference

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