DYNAMICS AND MIXING OF TRAPPED DROPLETS

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ABSTRACT

The problem of particle trapping and manipulation has a wide range of applications in biotechnology and engineering. Recently, a flow-based, particle-trapping mechanism called the Stokes trap was developed to allow for trapping and control of small particles in microchannels[1]. This mechanism consists of trapping particles in the intersection of multiple branches in a microfluidic channel. The motion of such particles can then be controlled by changing the flow rates in the branches. For deformable particles and vesicles, this mechanism can also be used to perform rheological experiments to determine the viscoelastic response of an emulsion or cell suspension[2]. Besides these applications, the various flow modes produced by the Stokes trap can also be used to manipulate the shape and even induce internal mixing in droplets. In this work, we analyze the dynamics of a droplet in a Stokes trap through boundary-integral simulations[3]. We also explore the response of drop shape with respect to distinct external flow modes, which allow us to perform numerical relaxation experiments such as step strain and oscillatory extension. A linear controller is also used to manipulate drop position, and the drop deformation is characterized by a decomposition of the shape into spherical harmonics. For droplets with small deformation (e.g., small radii and/or capillary number), we observe a linear superposition of harmonics that can be used to manipulate drop shape. We also investigate how the different flow modes may be combined to induce mixing inside the droplets by performing a mixing-number analysis[4]. The transient combination of modes produces an effective chaotic mixing inside the droplet, which can be further enhanced by changing parameters such as viscosity ratio and flow frequency.

PRELIMINARY RESULTS

In this work, we investigate the dynamics of a single Newtonian droplet in the intersecting region between six symmetrically distributed branches of a microfluidic channel with finite depth. To model the branch intersection, we consider a hexagonal prism as our computational domain. The problem geometry, as well as a sample simulation of a deformable droplet in such geometry, can be seen in Figure 1.

Figure 2 shows numerical simulations of mixing inside a droplet undergoing a three-phase extensional external flow mode for $a/H = 0.4, Ca = 0.1, W/H = 1$ and different values of viscosity ratio for different times. The droplet starts with a spherical shape with a passive dye in the lower region. The final configuration of the points is calculated by using the backward Poincaré cell method, where each grid point is traced back to its original position by numerically solving the reverse dynamical system. As expected from previous works[4], mixing is more effective for less-viscous droplets, as the inner velocity is larger in those conditions.

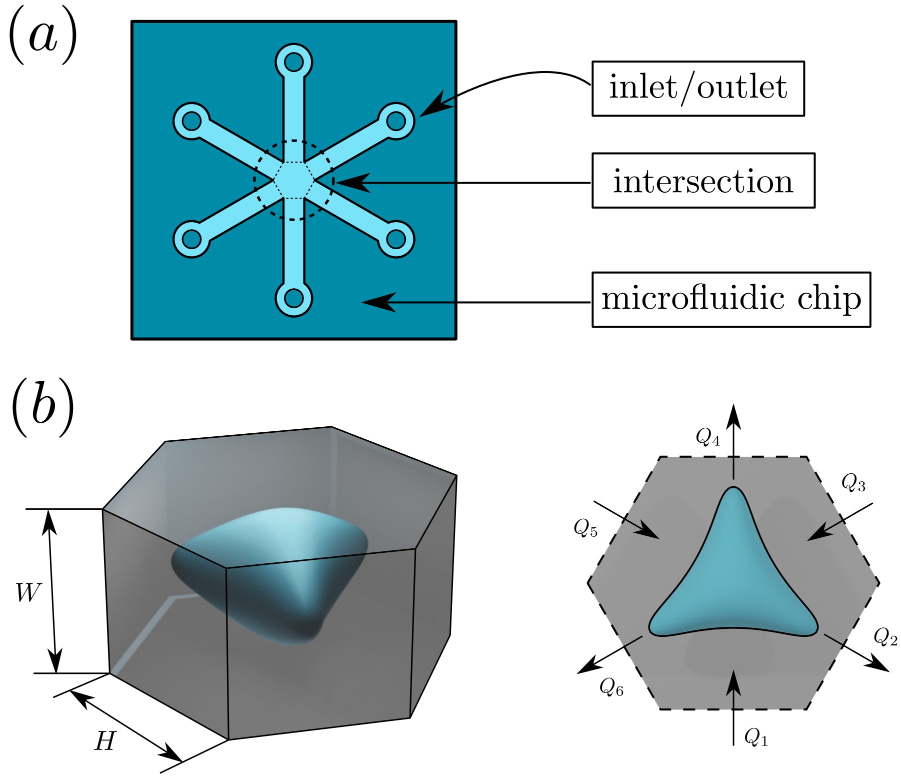

Figure 1: Geometry used for the numerical simulations of a droplet in a Stokes trap. The computational domain shown in (b) is an hexagonal prism corresponding to the intersecting region of the multiple rectangular channel branches, illustrated in (a). The flow velocity at each rectangular panel is given by a Boussinesq velocity profile with prescribed fluxes Q_i, which can be dynamically changed.

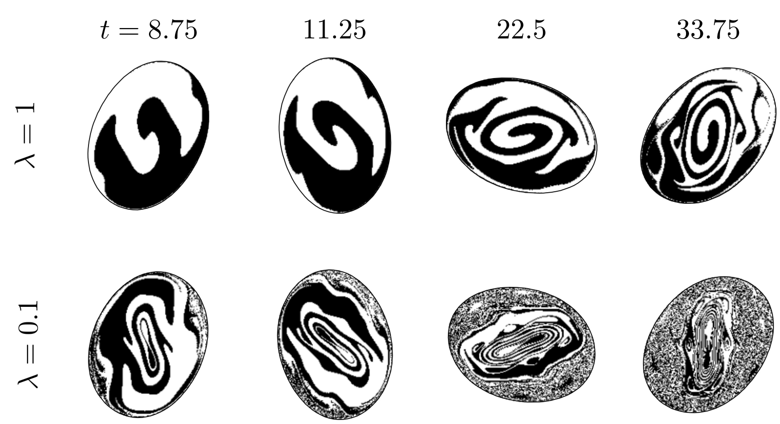

Figure 2: Numerical simulations of mixing inside a droplet undergoing a three-phase extensional flow for $a/H = 0.4$, $Ca = 0.1$, $W/H = 1$ and different values of viscosity ratio for different times. The results are for the midplane $z = 0$. Droplets with a lower viscosity ratio present a better mixing, which is indicated by a smaller mixing number.

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