Inertial Manipulation of Bubbles in Rectangular Microfluidic Channels

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Abstract

Bubbles trajectories in microchannel laminar flow can be controlled with fluidic forces. This effect finds applications in the field of electrochemical engineering. In this study, we investigate the bubble motion at moderate Reynolds number (1<Re<40) in rectangular microchannels. The important forces in the moderate Reynolds numbers are the wall-induced, deformation-induced, and the inertial lift forces. The equilibrium of these forces determines the final bubble lateral position in the channel. Numerical investigations are conducted with COMSOL Multiphysics® to demonstrate parameters that affect the bubble's equilibrium position. It resolves the fluid interface by the arbitrary Lagrangian Eulerian (ALE) moving mesh technique, where the interface is represented by exact mesh lines body-fitted with the bubble. The nondimensional incompressible Navier-Stokes equations are solved by using "Laminar Two-Phase Flow, Moving Mesh" interface. Because the viscosity ratio of the gas phase to the liquid phase is smaller than one, we assume that the viscosity ratio is zero. Therefore, we use external fluid interface at the interface of the bubble. Since the volume of the bubble is supposed to be constant, the pressure of the bubble can be obtained by imposing an additional constraint that the surface integral of the normal velocity on the bubble interface is zero. We perform the simulations in the reference frame that has the same streamwise translational velocity with that of the bubble. The advantage of adopting this frame is that the bubble only translates in the spanwise direction, viz., in the plane normal to the streamwise direction and is hence not advected out of the computational domain but still allowed to freely rotate and deform. Bubble velocity is a time-dependent unknown obtained at every time step, by adding an additional constraint that the surface integral of the streamwise velocity on the bubble interface is zero. We find that the Reynolds number, the Capillary number, the bubble diameter, and the channel aspect ratio are the influential parameters. The Reynolds number determines the balance of the different forces acting on the bubble. At small Reynolds values, the bubble equilibrium position is at the centerline. As the Reynolds number increases, the bubble gets closer to the wall and moves to the corner of the

channel on the diagonal. The capillary number signifies the ratio of viscous forces to the surface tension forces. The bubble equilibrium position is at the centerline at large Capillary number. By decreasing the Capillary number, the bubble moves to the wall. Lateral forces acting on the bubble originate from unequal pressure and velocity around the bubble. These parameters change as the diameter of the bubble varies. The equilibrium position of a small bubble is close to the wall while a larger bubble equilibrates closer to the centerline. Furthermore, in the channels with aspect ratios higher than on, the bubbles stay close to the wall. The numerical simulations are in good agreement with the performed experiments.

Figures used in the abstract

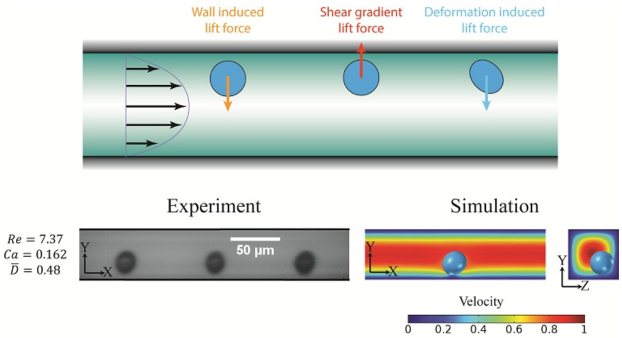

Figure 1: The position of bubbles in the rectangular microchannels can be controlled by tuning the balance of forces acting on them.