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RESEARCH PAPER

Electrokinetic transport and separation of droplets in a microchannel

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Abstract This work presents theoretical, numerical and experimental investigations of electrokinetic transport and separation of droplets in a microchannel. A theoretical model is used to predict that, in case of micron-sized droplets transported by electro-osmotic flow, the drag force is dominant as compared to the dielectrophoretic force. Numerical simulations were performed to capture the transient electrokinetic motion of the droplets using a two-dimensional multi-physics model. The numerical model employs Navier–Stokes equations for the fluid flow and Laplace equation for the electric potential in an Arbitrary Lagrangian–Eulerian framework. A microfluidic chip was fabricated using micromilling followed by solvent-assisted bonding. Experiments were performed with oil-in-water droplets produced using a cross-junction structure and applying electric fields using two cylindrical electrodes located at both ends of a straight microchannel. Droplets of different sizes were produced by controlling the relative flow rates of the discrete and continuous phases and separated along the channel due to the competition between the hydrodynamic and electrical forces. The numerical predictions of the particle transport are in quantitative agreement with the experimental results. The work reported here can be useful for separation and probing of individual biological cells for lab-on-chip applications.

1 Introduction

The developments in microsystems technology (Sen et al. 2006, 2007, 2011; Sen and Darabi 2007, 2011; Bhardwaj et al. 2011; Bhardwaj and Sen 2012; Goet et al. 2013) lead to an increasing interest on the methodology to realize desired motion of micron-sized objects in a solution environment. The electrokinetic phenomena have been widely used for transportation and manipulation of micron-sized objects including colloidal particles and biological cells in lab-on-chip devices using electric fields (Dolnik et al. 2000; Leopold et al. 2004; Kang and Li 2009). In electrokinetics, the motion of objects is referred to the migration of charged objects suspended in aqueous solutions subjected to externally applied electric fields. The particle motion is governed by the interaction between the applied electric field and the net charges on the surface of the object and within the electrical double layer (EDL) adjacent to the charged surface. The design of devices for manipulation and control of particle transport relies on a thorough understanding of the interaction between the micron-sized objects and the fluid flow. If a DC electric field is applied to two-phase flows present in a microchannel, the motion of the micron-sized objects is induced by the electrophoretic force acting on the particle and electro-osmotic fluid motion (Barman et al. 2013; Kemprai and Sen 2012) arising from the surface charges at the channel walls. In the case of spatially non-uniform electric fields, dielectrophoretic (DEP) effect becomes significant along with the electrophoretic and electro-osmotic effects due to the induced dipole moment on the objects, which should be taken into consideration (Ai et al. 2000, 2010). Among various kinds of micron-sized objects, droplets with a diameter of the order of ten microns have recently attracted attention as a convenient model of living cells (Pietrini and Luisi 2004; Tawfik and Griffiths 1998; Hase and Yoshikawa 2006).

From the literature review, it is observed that some theoretical analyses (Keh and Anderson 1985; Ye and Li

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