ABSTRACT

Manipulation of deformable, fluid-filled globules, e.g., drops and vesicles, owing to the complex interfacial structure, has emerged as a thriving research topic in viscous force-dominated fluid flow under micro-confinement. Diverse practical applications associated with these multiphase fluid encapsulations include targeted drug delivery using artificial microswimmers, modelling of biological cells, e.g., human erythrocytes and leukocytes as drop or vesicle model, encapsulation of bacteria and other living organisms inside a drop or vesicle template serving as micro-reactor for biomedical studies, food processing, chemical industries, etc. to name a few. In addition, the type of flow actuation and geometrical constraints play pivotal roles in altering the induced flow field. These results in alerted hydrodynamic stresses acting on the soft particle, causing deformation and shape transition in a nontrivial manner. Moreover, the application of electric field and surface impurities serve as promising means for manipulating such fluid-filled encapsulations in the paradigm of Lab-on-Chip microfluidic technology, which exploits the electrical stress and the surface tension gradient-driven Marangoni stress for trajectory manipulation in a controlled fashion.

Despite outstanding research advancements in particle manipulation and sorting at microscale, numerous issues related to interfacial electro-hydrodynamics still need to be better understood. This includes the coupling between electromechanics and interfacial dynamics, which becomes more complex as the description of the interface changes from a simple fluid-fluid one to a membrane-fluid interface in a tightly confined domain where the wall effects become substantial. Motivated by these, the present thesis attempts to systematically explore several unresolved facets of fluid dynamics associated with complex interfaces. In addition, the influence of transverse electrical forcing and interfacial impurities on the deformation and migration characteristics of such deformable globules has been thoroughly investigated. The present thesis targets three primary, fluid-encapsulated systems, namely: (a) electrical control of a *surfactant-laden single drop* in Poiseuille flow; (b) Migration and pinch-off characteristics of a *compound drop* exploiting the interplay of electromechanics and hydrodynamics; (c) Probing dynamical regimes of a *lipid vesicle* (representing membrane-fluid interface) in flow through a constricted channel.

In order to solve the problems mentioned above, theoretical and experimental approaches have been adopted. First, suitable theoretical models are developed to strengthen the understanding on the associated physics and to explain the experimental findings. On numerical modelling perspectives, the two-phase droplet systems and their interfaces have been traced by phase-field model. Here, the fluid-fluid interfaces are resolved by incorporating smooth variations of the phase field parameter ranging between two integer values. On the contrary, the membrane-fluid interface is tackled numerically by the Boundary integral method (BIM) using Green's function approach. Additionally, controlled experiments were executed to validate the theoretical models proposed in this dissertation. Considering the fluid phases to be leaky dielectrics, numerical simulations are performed to obtain the deformation and cross-stream migration of the drops located between two parallel plate

electrodes. An electrode-embedded, compact, lab-on-chip device has been fabricated to facilitate the experiments associated with the electrical field.

The results and methods presented in this thesis open up exciting avenues toward tuning the direction of migration and deformation characteristics of a confined fluid-encapsulated compartment by selectively exploiting the interplay of electrical forcing, surface tension gradient-induced stress, and hydrodynamic stresses. The findings and conclusions from this thesis related to the maneuvering of deformable entities through micro-sized channels have decisive implications in engineering and biological sciences.

Keywords: Electrohydrodynamics, Leaky Dielectric, Drops, Giant unilamellar vesicles, Shape deformation, Lateral migration, Bending modulus, Dilatational modulus, Reduced area, Reduced volume, Eccentricity, and Neck thickness.