ABSTRACT

The aim of the present dissertation is to investigate the effect of surface tension gradient on the dynamics of droplets and emulsions in the presence of an imposed flow field. This surface tension gradient, which gives rise to the Marangoni stress at the interface, can be generated as a result of any of the following three mechanisms: (i) application of a temperature gradient in the flow field, (ii) addition of bulk-insoluble surfactants on the surface of the droplet suspended in an imposed fluid flow and (iii) combined presence of both surfactants and an imposed temperature gradient in the flow field. Here, a general mathematical model is developed to study the effects of Marangoni stress on the dynamics of a Newtonian droplet in the creeping flow regime. An outstanding question concerning the resultant non-trivial dynamical features that is addressed in this thesis pertains to the nonlinearity associated as a consequence of the convective transport of surfactants along the interface and shape deformation, which does not permit to analyze the combined effect as a linear superposition of the results for the thermocapillary and imposed flow driven droplet dynamics, in an effort to obtain the final solution.

In order to address practical microfluidic setups, the influence of a bounding wall, fluid inertia and finite shape deformation on the cross-stream migration of the droplet is investigated through numerical simulations. This is the prime objective of the first study, where a surface tension gradient is generated as a result of application of a constant temperature gradient in a direction transverse to the imposed Poiseuille flow. This study shows that a larger droplet migrates towards the channel centre whereas a smaller droplet migrates away from the channel centreline for a fixed channel height. Towards studying the effect of surfactants distribution on migration as well as deformation of a droplet in the presence of an incipient flow, a small deformation asymptotic approach is adopted for the two limiting cases of convective and diffusive mode of surfactant transport. These studies show that the Marangoni stress, generated as a result of the nonuniform distribution of surfactants along the interface, induces retardation in the cross-stream migration of the droplet but enhances the deformation of droplet as well as the effective viscosity of an emulsion. A separate experimental study is also performed to study the effect of channel confinement on the cross-stream migration of a surfactant-laden droplet in a Poiseuille flow. This

study provides evidence to the fact that presence of surfactants brings in reduction in the cross-stream migration velocity of the droplet.

Later the combined presence of surfactants and a constant temperature gradient is considered and its effect on the migration of droplet, suspended in an imposed Poiseuille flow, is investigated over two separate studies. In the first study a spherical droplet is assumed, however, two separate physical systems are considered, namely, a buoyant and a neutrally-buoyant system. An asymptotic approach is used in this study which shows that although the temperature gradient as well as the buoyancy force act in the axial direction, the cross-stream migration velocity of the droplet is significantly affected in the presence of either or both of them. Following this, a small deformation asymptotic analysis is performed in another study to show the effect of shape deformation and a constant temperature gradient on the cross-stream migration velocity of the droplet.

Throughout the thesis, the physical explanations and reasoning of the results facilitate the science and engineering community towards a better understanding of the different concepts related to the migration and deformation of droplets in the presence of varying surface tension and an incipient flow. The different outcomes from the studies prove that the dynamics of droplets can be precisely controlled by the effective use of surface tension gradient as a tool. These concepts underlying the fine-tuned control of droplet dynamics bear significant consequences in the design and development of droplet-based microfluidic systems.

Keywords: Marangoni stress, surface tension, droplet, emulsion, shape deformation, temperature gradient, surfactant distribution, surface convection and diffusion