Abstract

This thesis presents a numerical study on the electrohydrodynamics of an uncharged dielectric colloid as well as charged dielectric colloids and liquid droplets under the influence of an external electric field through an electrolyte or hydrogel medium. The mathematical model is based on conservation principle, which leads to the coupled set of Navier-Stokes-Poisson-Nernst-Planck equations. The Brinkman extended Navier-Stokes model is used to formulate the flow through the gel medium. Chapter 1 of the thesis is introductory.

In Chapter 2, we consider the electroosmotic flow (EOF) around an uncharged dielectric spherical particle under the influence of an imposed electric field with the dielectric decrement effect. Our investigation shows that the EOF not only depends on the applied electric field strength but also with the Debye layer thickness as well as with the particle permittivity. The flow enhances as the particle dielectric permittivity becomes higher and the Debye length becomes thinner. The dielectric decrement effect creates a reduction in the EOF.

The electrophoresis of a dielectric charged colloid with hydrophobic surface in an electrolyte/charged hydrogel medium is studied in Chapter 3 and 4, respectively. We have estimated electrophoretic mobility through the balance of forces experienced by the particle for a wide range of electrokinetic parameters. The hydrophobicity of the surface enhances the fluid convection in the Debye layer, which in turn amplifies the particle mobility. The solid polarization of the particle, the double layer polarization and relaxation as well as surface conduction are also influenced by the surface hydrophobicity. In addition to that, these effects create a nonlinear variation of electrophoretic velocity with surface charge density and external electric field.

Subsequently in Chapter 5, we present the electrophoresis of a pH-regulated polyelectrolyte nanogel by considering the ion partitioning effect. The charge properties and hence, the mobility of the nanoparticle depends on functional groups present in the polyelectrolyte as well as on the electrolyte concentration. The ion partitioning effect arising due to the difference in permittivity of the two mediums creates an enhancement in electrophoretic mobility. The ion partitioning effect is pronounced for a larger polyelectrolyte functional group concentration and higher electrolyte concentration. The impact of nonlinear effects such as counterion condensation, double layer polarization, and relaxation along with the ion partitioning effect is analyzed.

The electrophoresis of a charged liquid droplet/bubble is presented in Chapter 6 and 7, respectively. A decrease in droplet viscosity increases the fluid convection on the droplet surface, which enhances the droplet mobility. Our results show that the surface conduction effect becomes significant with the occurrence of slip velocity at the droplet surface which attenuates the droplet mobility. The surface conduction effect distinguishes the electrophoresis of a viscous droplet from that of a rigid colloid. The droplet viscosity also affects the double layer polarization and relaxation effects. The dielectric polarization reduces the electrophoretic velocity and its impact is stronger for a droplet of higher viscosity when the Debye length is in the order of the droplet size. The slip velocity at the bubble interface driven by the Maxwell stress acts opposite to the direction of translation of the bubble. This creates a difference in electrokinetics of a bubble from a rigid particle or drop of higher viscosity. The role of shear stress at the gas-liquid interface and surface conduction effect on electrophoresis of a bubble is analyzed.

Keywords : Counterion condensation; Dielectric polarization; Double layer polarization; Electrophoresis; Electrophoretic mobility; Hydrophobicity; Induced charge electroosmosis; Ion partitioning; Nernst-Planck equations; Numerical solution; Surface conduction.