ABSTRACT

The primary focus of the present dissertation is to showcase the micro-scale transport phenomena of complex fluids whose rheology alters in presence of an electric field and a flow field. Fluids whose rheology exhibit strong functional dependence of an electric field presence are known as Electrorheological Fluids (ERFs). In this thesis, two broad categories of such ERFs, namely, the Dielectric ERFs (a heterogeneous ERF – a suspension of dielectric particles in a dielectric continuous phase) and the Nematic Liquid Crystals (a homogeneous ERF – a single-phase continuous medium) have been investigated. More precisely, electrorheologically-modulated dynamics of these two most common varieties of ERFs are analyzed. Fluid is considered to be confined in a microfluidic environment, exhibiting a rich plethora of electrohydrodynamic behavior. To this end, a detailed formulation of the equations governing the dynamics of DER fluids and NLC media is derived.

With a generic depiction of the underlying electro-hydrodynamic equations, the fundamental problem related to the capillary filling dynamics of DER and NLC fluid is addressed and studied under the framework of reduced-order formalism. The coupling influences of electrocapillary phenomena, gravity and viscous effects are incorporated in the model framework to investigate the rate of capillary front rise and final equilibrium height attained. Contrasting features in capillary filling characteristics are observed for the two types of fluids under concern. The evaluation of the temporal evolution of capillary front is followed by a comprehensive scaling analysis that demarcates the distinctive regimes of the capillary dynamics. Further, an experimental perspective is included in these studies to validate the predictive capability of the developed theoretical model.

An essential aspect in studies regarding the microfluidic transport processes is the concept of Electrokinetics – a phenomenon which concerns with flow modulations in presence of an induced Electrical Double Layer (EDL). Electrokinetics of ER fluids is a very novel concept wherein an EDL, spontaneously induced via certain physico-chemical reaction between the ER fluid and its confining substrate, provides a component of the electric field necessary for ER activation. Towards this, two separate electrokinetic phenomena exploiting the intricate ER characteristics of such complex fluids are studied.

First, the case of spontaneously generated ER behavior due to EDL induction in a concentric cylindrical annular (Taylor-Couette) configuration is looked into. It is noted that for both DER and NLC fluids, torque transfer between the annulus gets augmented due to the presence of EDL, although the flow characteristics show sharp contrast for these two fluids. Since the DER flows are characterized by plug-like zone, a further scaling analysis is performed to implicate the plug-zone formation to the observed ER effect. The NLC medium, on the other hand, exhibits intriguing shear thinning and shear thickening phenomena under different circumstances. Description of such an observation, which showcases the ER effect, has also been attempted. Subsequently, electroosmosis of DER and NLC fluids is studied. The DER fluids show exciting flow characteristics for variable strength ratios of the EDL and the applied electric fields, whose comprehension through a scaling analysis brings forth the existence of different flow regimes. The electroosmosis of NLC exhibit interesting electrorheologically-induced flow inversion behavior which is validated through a molecular dynamics simulation that is developed and performed for similar flow configuration. The induced ER nature along with the involved viscoelastic properties of the NLC medium is also highlighted.

The problems addressed in the present thesis and the outcome from these investigated issues will be a precursor to future rigorous experimental and numerical studies related to ER-modulated flow in micro-confinement. The findings will further help in understanding the underlying mechanism behind ER-modulated flows and facilitate the designing of futuristic smart micro-devises based on the fundamental concepts addressed here.

Keywords: Electrorheological Fluids, Dielectric Electrorheological Fluids, Nematic Liquid Crystals, Capillary filling dynamics, Taylor-Couette flow, Electrokinetics, Electroosmosis, Bingham model, Casson model, Ericksen-Leslie-Parodi (ELP) model