

## ABSTRACT

The utilisation of electric field in flow actuation and droplet manipulation has garnered significant attention in academic research in recent times due to its broad range of potential applications spanning various fields, including engineering and medicine. The interplay between electro-mechanics and fluid rheology over interfacial scales has resulted in the emergence of numerous micro-scale and nano-scale fluidic devices. The utilisation of polymeric fluids to replicate complex fluids is becoming increasingly pertinent in various process industries, such as food engineering, chemical processing, and oil recovery. The aforementioned applications serve as a clear demonstration of the crucial role played by fluid rheology in comprehending the fundamental functionalities. Consequently, the study of droplet hydrodynamics and fluid flow of complex fluids in relation to electromechanics has emerged as a burgeoning area of research in recent years. In spite of noteworthy progress in the discipline, certain crucial facets pertaining to the electro-hydrodynamics of singular viscoelastic droplets and the electrokinetics of continuous viscoelastic fluid flow remain uninvestigated, constituting the principal focal points of this thesis.

Towards addressing the above, first, a theoretical model for salinity gradient induced flow of polymer electrolyte solution through a microchannel is formulated. The purpose of this model is to confirm the experimental findings that suggest an increase in the induced potential due to the elasticity imparted by the presence of trace amount of polymer in the fluid. A simplified Phan-Thien-Tanner (sPTT) model is used to represent the flow dynamics of the dilute polymeric fluid solution. The augmentation in the salinity gradient induced electric potential is only observed when the addition of polymer increases the elasticity of the fluid while negligibly changing its viscosity. The findings orchestrate the role of viscoelasticity and complex rheology inculcated through addition of trace amount of polymer in augmenting the salinity gradient induced electric potential.

Following the foundations of possible augmentation in induced potential achieved through viscoelastic fluids, the physiological significance of induced streaming potential due to flow of electrolyte through microfluidic passage with charged surfaces is explored via interaction between the negatively charged poroelastic endothelial glycocalyx layer (EGL) lining the inner walls of micro-vessels with blood plasma consisting of ions. The intricate rheological properties of a fluid that mimics blood are elucidated by utilising a Newtonian fluid model to represent the blood plasma and a viscoelastic fluid model to represent the entirety of the blood. The results indicate that micro-flows that are physiologically relevant generate streaming potential suitable for powering biosensors and implantable medical devices, which typically require micro to milli Watt power. Thus, by addressing the interplay between the viscoelastic nature of blood and the negatively charged poroelastic EGL, the induced streaming potential and its physiological applications are explored.

The modelling of various industrial and biological fluids as continuous viscoelastic fluids has given insights crucial for many applications. However, a comprehensive understanding of the impact of electrical actuation on such fluids necessitates the consideration of the effects on individual fluid entities, such as droplets. Out of many, droplet hydrodynamic phenomena, merging of isolated liquid drops is a common phenomenon that may greatly be influenced by adding polymeric contents to the liquid imparting a viscoelastic characteristic on the fluid. A crucial aspect in droplet coalescence is controlling the merging of two isolated droplets to determine the bridge growth dynamics during the formation of final daughter droplet. An exclusive control on the dynamics of the intermediate liquid bridge formed is achieved via exploiting the interactions of an exciting AC electric actuation with a trace amount of polymeric inclusions present in the intermingling drops. These experimental findings are further rationalized by a simple unified theory unravelling a universality of temporal growth of liquid bridge at early times.

Since, viscoelasticity adhered due to polymer inclusion significantly alters the merging dynamics of droplets subjected to electrical actuation, the electro-wetting dynamics of a polymeric viscoelastic droplet is further explored by mapping the droplet response towards external stimuli with its rheology. Dilute polymeric fluids as well as many biological viscoelastic fluids have very low relaxation times, determination of which is time consuming, expensive and complex to replicate in a lab setup. To address this, a novel methodology based on oscillatory electrowetting response of tiny droplet analogous to a free mass spring dampener vibrating system is explored. By corroborating well with the reported values of the relaxation times as obtained from more elaborate and sophisticated laboratory set-ups, the findings provide perspectives for a unique and simple approach towards electrically-modulated on-chip-spectroscopy for deriving ultra-short relaxation times of a broad class of viscoelastic fluids that could not be realized thus far.

Findings of the different problems investigated in this work are likely to offer new insights in the understanding of electromechanics of both viscoelastic fluid flow and viscoelastic fluid droplets, bearing significant implications in process industries and biomedical technologies. Further scopes of advancement include probing the role of viscoelastic rheology coupled with electrical actuation towards applications such as, augmented energy conversion in charge modulated surfaces through coupled thermal gradients and enhanced mixing of droplets by using semi-dilute polymeric solutions. It could be extended to physiological fluid droplets by providing a contactless approach of testing blood samples without needing any test reagents, simply by recognizing the patterns of nonlinear electro-mechanical responses of a spreading drop having several applications at the interface of microfluidics and healthcare.

**Keywords:** Electrokinetics, Streaming potential, Salinity gradient induced potential, Viscoelastic Fluid, Electro-wetting, Electro-coalescence.