ABSTRACT

Modulating drop dynamics using electric field is popular among the modern approaches of drop manipulation, adopted in a wide variety of applications, starting from industrial applications like oil purification and ink-jet printing to biomedical applications like cell handling and targeted drug delivery. The **drop electrohydrodynamics (EHD)** has been a hot topic of research over the last few decades, primarily due to the complex yet interesting physics associated with the mechanisms evolving at the electrically stressed interfaces such as electrohydrodynamic flow, charge convection, and interfacial deformation dictated by the interaction between hydrodynamic, electric, and capillary forces at different scales. Despite many previous investigations, several facets of drop EHD remain partially understood or fully unexplored, addressing which is the primary objective of the present dissertation.

Three different topics of immense practical significance are investigated: (i) EHD of gravity-driven drop settling, (ii) EHD of drops in the background in extensional flow and post-cessation of flow and (iii) EHD interaction between the drops. The different physical limits are identified in terms of the degree of drop deformation and the relative dominance of viscous or inertial, or capillary forces. The EHD of slightly deformed drops under viscous flow limit (or Stokes limit) is addressed using analytical and semi-analytical models integrated with nonlinear charge-convection effects. The different flow regimes and deformation limits (which include breakup regimes) are investigated using numerical simulations.

Electric-field-induced deformations are found to be a significant factor in altering the settling speed of buoyant drops. Besides, surface charge convection can solely alter the drag forces acting on the settling drops by inducing asymmetry in electric and hydrodynamic stresses, resulting in a consequential increase or decrease in settling speed depending on electrophysical properties. However, the combined influence of the above two factors on settling speed considerably diverges from the simple superposition of their individual effects since the degree of deformation is itself a function of charge convection. Importantly, in the Stokes flow regime, the transient deformation is monotonic, whereas deformations can follow a nonmonotonic path in the inertial flow regime. Furthermore, in the former physical limit, charge convection results in asymmetric-spheroidal drop shapes, whereas in the latter, more complex topological modulations, for example, dimple formations, can be seen.

The combinatorial impact of electric field and background extensional flow can generate highly elongated drop shapes, the stability of which can be challenged by exploiting surface tension-driven instabilities post-flow-cessation. In the second set-up, the morpho-dynamic evolution of drops in the period of pre and post-withdrawal of the uniaxial extensional flow is studied under electric field. It is shown that electric field can guide the transient relaxation to a stable shape or promote breakup by mid-pinching or end-pinching. The non-breaking modes (or stable) and breakup modes are found to be dependent on pre-relaxation topology and relaxation rate, which is explained by virtue of simplified theoretical formulations.

Next, the inertio-capillary dominated coalescence of two unequal-sized drops is investigated under electric field, with an intention to explore the field effects on secondary/daughter drop generation. The present study elucidates that electric field can dramatically modulate the effects of size ratio and viscous resistance and thereby modify the outcome of coalescence e.g. transition between complete and partial coalescence and the topology of secondary/daughter drops. Notably, strong electro-capillary forcing can lead to pinch-offs via cusping mode or end-pinching. The daughter drops eventually come into contact with the parent drops to initiate self-similar events or coalescence cascade. It is observed that under electric field, the number of successive pinch-offs non-monotonically varies with size ratio.

To probe the functionality of electric-field-driven drop-drop interactions, the dynamics of undeformed eccentric compound drop suspending in a quiescent medium is studied under uniform electric field. Using a bispherical coordinate-base theoretical formalism, it is shown that eccentricity introduces asymmetry in electric field and flow field in the drop proximity. This generates net EHD force and dielectrophoretic (DEP) drag on the drop, which causes the translation of the inner and outer drop in the direction or opposite direction of electric field. As, depending on the direction of migration and the relative velocity between the drops, the eccentricity may further increase or decrease, the drop may continue to move or eventually attain a stationary state.

The findings presented in this thesis explain the role of the electric field in altering the existing drop dynamics or activating novel facets in drops. These findings provide scope for the development of novel techniques of drop manipulation in many industrial, microfluidic, and biomedical applications.

Keywords: *drop, charge convection, shape deformation, coalescence, compound drop, migration*