Study of Bubble and Droplet Dynamics at Different Length and Time Scale

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Doctor of Philosophy

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Abstract

Drops and bubbles are omnipresent in natural and engineering processes, including raindrops on the soil, droplets from breaking waves, transmission of respiratory diseases, inkjet printing, combustion, cooling spray, antifreeze, additive manufacturing and surface coating. The dynamics of droplets and bubbles play a significant role in these aforementioned processes. Due to the dominance of surface tension force over the inertial and viscous force, understanding the dynamics of droplets and bubbles in different types of liquids is of great importance. The dynamics of bubble/droplet have attracted researcher's attention from several decades as the behaviour of droplet/bubble is significantly different from the behaviour of the fluid in bulk phase. The advent of micro/nano technology is causing the focus to shift from the macro scale to the micro/nano scale with the aim to produce bubble/droplet within micro/nano fluidic confinement. Such production and manipulation of droplet/bubble at micro/nanoscale requires precise control and a detailed understanding of the flow physics especially when the length and time scale are significantly small. When the droplet/bubble are within a micro/nano fluidic confinement or a nano-scale droplet is in contact with a free solid surface, the structural and dynamic behaviour of the droplet/bubble are driven by a number of factors such as geometry of the confinement, fluid property, viscosity, surface tension, contact angle, gravity, external forces (thermal, magnetic or electric field). The enormous applications of droplets and bubbles at micro/nanoscales and the complexity involved in the micro/nanoscale fluid dynamics trigger the research interest in this fascinating area. In the present thesis, the whole research was divided into two different aspects. One is the bubble dynamics in microfluidics confinement where continuum assumptions are valid and another is the nanodroplet dynamics on a solid surface subjected to external forces where continuum assumptions are no longer applicable. However, for fluid dynamics at nanoscale, it is very difficult to get reliable experimental data and therefore, the study of droplet/bubble dynamics at nanoscale is mostly conducted through the route of computer simulations. For the study of bubble dynamics at micro-scale, two-phase gas-liquid Taylor flow regime was considered due to its enormous applications in the chemical and related industries. For the investigation of droplet dynamics at nanoscale, an ion-water nanodroplet on a free solid Pt surface was considered under the influence of external electric fields (here electric field was considered as external force due to its wide range of applicability). The study of Taylor bubble dynamics inside microfluidic channels was conducted both experimentally and using continuum mechanics based computational fluid dynamics (CFD) simulations. To study the nanodroplet dynamics, molecular dynamics (MD) simulations were used. This thesis helps to interpret different aspects of droplet/bubble dynamics at

two different length and time scales. The results show that the dynamics of bubble formation in microfluidic channels are greatly influenced by the gas-liquid superficial velocity ratio, nature of the channel surface, static contact angle, geometries of the channels, viscosity of the working fluid, surface tension and nature of the working fluids etc. Presence of curvature within the channel significantly influences the bubble dynamics. The dynamics of Taylor bubble in the presence of non-Newtonian continuous phase is much more intriguing and complex as compared to the non-Newtonian continuous phase. The thesis reveals some interesting observations on the Taylor bubble dynamics in presence of non-Newtonian shear thinning continuous phase. The study of nanodroplet dynamics in free solid surface under external electric field elucidates some details about the evaporation and spreading dynamics and also about the formation of nanocolumns under the vertical electric fields. The nanoscale droplet dynamics also provides an insight into the rearrangements of molecules near the solid-liquid interface and the bulk phase under the influence of external electric fields.