

Abstract

In this thesis, we have conducted a sequence of numerical studies using the Volume of Fluid (VOF) method to investigate the inertial deformation of a droplet and its interaction with a bubble in a quiescent water medium. First, we examine the droplet deformation under initial momentum for a range of Weber numbers ($13 \leq We_d \leq 200$) and Ohnesorge numbers ($0.0001 \leq Oh_d \leq 0.01$). Here Weber number ($We_d = \frac{\rho_d V_0^2 d_d}{\sigma_{dl}}$), represents the ratio of inertial force to interfacial tension force, where, ρ_d , V_0 , d_d , and σ_{dl} denote the density, initial velocity, diameter, and interfacial tension of the droplet, respectively. Ohnesorge number ($Oh_d = \frac{\mu_d}{\sqrt{\rho_d d_d \sigma_{dl}}}$), where μ_d is the droplet viscosity. The results reveal that the initial momentum of the droplet generates a toroidal vortex and a rear-side jet, whose strength increases with We_d , leading to distinct jet regimes such as weak jet, short jet, and strong jet. A semi-analytical model was developed to predict the maximum jet velocity as a function of We_d and Oh_d , showing that jetting becomes significant beyond $We_d \approx 48$. We carried out this study further for the inertial stage of jet evolution ($1.4 < t/\tau_d < 2.8$) for different We_d values up to 708, the jet interface exhibits self-similar behavior dominated by inertia, where rescaled profiles collapsed onto a single curve. The scaling followed a distinct temporal exponent of $1/2$, showing the inertial regime. Extending these insights to bubble-droplet interactions, we analyzed head-on collisions for size ratios between 0.5 to 2 and We_d up to 270, identifying four collision regimes that describe the sequence from smooth attachment to strong jet penetration through the droplet and bubble. For higher We_d , droplet breakup occurs as the jet stretches the droplet after a certain length ($\mathcal{L}_{max} > 3.18d_d$). This breakup gets suppressed by the presence of the bubble. Jet formation is decisive in attachment and breakup processes, with regime transitions controlled by We_d and bubble to droplet size ratio. Together, these studies provide a comprehensive understanding of inertial droplet deformation, jet evolution, and bubble-droplet collision dynamics, offering physical insights and predictive models relevant to multiphase systems in applications such as wastewater treatment and related engineering processes.

Keywords: Bubble-droplet interaction. jetting, self-similar analysis, droplet deformation.