CFD studies on bubble/droplet formation in microchannels

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Abstract:

In recent years, bubble/droplet–based microfluidics offers a wide range of applications in the fields of lab–on–a–chip, chemical, biological and nanomaterial synthesis. In such systems, the rheology of fluid considerably influences droplet/bubble formation characteristics when non-Newtonian fluids are involved. This work aims to systematically investigate the influences of non-Newtonian properties on the physical process of droplet/bubble formation at the microscale. Two-phase Volume-of-Fluid method (VOF) and Coupled Level Set and Volume of Fluid (CLSVOF) formulations are employed to capture the droplets/bubbles breakup dynamics and relevant hydrodynamics. Systematic investigation in various microfluidic configurations are carried out to examine the effect of various controlling parameters.

Firstly, a CFD model is developed to understand the Taylor bubble behavior in Newtonian and non-Newtonian liquids flowing through a confined co-flow microchannel. Simulations are methodically carried out to explore the influence of surface tension, inlet velocities, and apparent viscosity on the bubble length, shape, velocity, and film thickness around the bubble. Furthermore, formation and dynamics of Taylor bubble in power-law and Carreau liquids flowing through a circular co-flow microchannel are numerically investigated. Based on the bubble length with respect to the channel diameter, three different bubble shapes are identified. For the first time, flow pattern maps are constructed based on inlet velocities for power-law and Carreau liquids. Additionally, scaling laws are proposed to estimate the bubble length in such configuration.

Later, a three-dimensional CFD model is developed to analyse droplet formation in the flow-focusing and T-junction microchannels. Various influencing factors such as continuous and dispersed phase flow rates, and interfacial tension are examined to understand the droplet formation mechanism. Three different regimes, viz., squeezing, dripping and jetting are observed in a T-junction microchannel. The genesis of Newtonian droplets in non–Newtonian liquid is also numerically studied and characterized in a T-junction microchannel. It is found that rheological parameters have significant influences on the droplet length, volume, and its formation regime.

Keywords: Computational fluid dynamics; Taylor bubble; Droplet; Microfluidics; Non-Newtonian liquid; Two-phase flow; Flow regime