INDIAN INSTITUTE OF SCIENCE

Abstract

Division of Mechanical Sciences

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Doctor of Philosophy

Liquid bridge breakup and detachment dynamics investigated using dynamic domain multiphase flow simulations

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Liquid bridges, formed between two solid surfaces in close proximity are encountered in a variety of engineering and daily life applications. The dynamics of a liquid bridge including its evolution that typically involves necking, rupture and eventual detachment from the solid surfaces depend largely on the contact line motion. Accurate modeling of the motion of the three-phase contact line is therefore a critical aspect and a significant challenge in simulation based investigations of liquid bridge dynamics. Additionally, the dominance of surface tension forces, especially close to the rupture, and the high density contrast between the liquid bridge and the surrounding medium make this task even more difficult. To overcome these challenges we develop a moving domain diffuse interface flow solver based on Cahn–Hilliard phase field model for multicomponent incompressible flows. The motion of the continuously expanding physical domain is adapted into a time-independent computational framework using generalized coordinate transformation methodology. In essence, the transformed Navier-Stokes Cahn-Hilliard equations are solved on a time-independent stationary computational domain using a standard second-order accurate conservative cell-centered finite-volume spatial discretization and semi-implicit Adam-Bashforth Backward-Differentiation temporal integrator. Moreover, to overcome the stiffness of the fourth-order spatial operator in the Cahn-Hilliard equation, a splitting approach that relies on two coupled Helmholtz equations to improve numerical stability at moderate CFL numbers is formulated. Both the coupled Helmholtz equations and the constant coefficient type pressure Poisson equation are solved using a highly efficient fully parallelized block-tridiagonal direct solver. The accuracy and the efficiency of the moving domain diffuse interface method is assessed on a range of test cases involving high density ratios, surface tension forces and the three-phase contact line motion.

Next, utilizing our moving domain diffuse interface multiphase flow solver we investigate the temporal evolution of a water liquid bridge in the surrounding air medium on an ever expanding computational domain. The boundaries of the time dependent physical domain coincide with the stationary and moving planar hydrophobic surfaces that support the liquid bridge. Simulations reveal that the temporal evolution of the liquid bridge can be classified into six distinct regimes. At a low Reynolds number of 0.1, in general, the entire liquid volume adheres to the less hydrophobic surface while a complete detachment regime is observed for highly hydrophobic stationary and moving surfaces. For contact angles greater than about 118 degrees, a two lobe zone in which liquid adheres to both the surfaces is observed. The contact angle beyond which the two lobe zone is observed decreases with an increase in the Reynolds number. Furthermore, additional regimes namely the complete detachment regime in which the liquid bridge detaches completely from both the stationary and moving surfaces, and the satellite drop formation regime are also observed. The dependence of these regimes on the Reynolds number and the contact angles prescribed at the stationary and moving surfaces is investigated. The self-similarity of the retreating dynamic radius on each of the stationary and moving plates is analyzed in detail.