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High fidelity anisotropic adaptive variational multiscale method for multiphase flows with surface tension

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Abstract

We propose in this work an adaptive variational multiscale method for two-fluid flows with surface tension. A level set function is used to provide a precise position of the interfaces. The implementation of the surface tension in the context of the Continuum Surface Force is proposed to circumvent the capillary time step restriction. The obtained system is then solved using a new derived Variational Multiscale stabilized finite element method designed to handle the abrupt changes at the interface and large density and viscosity ratios. Combined with an a posteriori error estimator, we show that anisotropic mesh adaptation provides highly stretched elements at the interfaces and thus yield an accurate modeling framework for two-phase incompressible isothermal flows. Stable and accurate results are obtained for all two- and three-dimensional numerical examples. To the best of our knowledge, these are the first simulation results for representative time-dependent three-dimensional two-fluid flow problems using an implicit treatment of the surface tension and a dynamic unstructured anisotropic mesh adaptation.

Keywords: Surface tension, Multiphase flows, Level Set, Variational MultiScale method, Anisotropic mesh adaptation, 2D & 3D rising bubble, Rayleigh-Taylor instability

1. INTRODUCTION

Many essential features in hydrodynamics are accessible only through extremely detailed analysis that capture different spatial and temporal scales set by the physics and the geometry of the problem. This includes a multitude of applications with great scientific interest such as microfluidic cell separation in biology [1], droplet coalescence in chemistry [2], micro-fabricated platforms for cancer diagnosis [3], emulsion in food industry [4], and more. For various reasons, these multi-fluid applications are very hard or impossible to investigate experimentally, and thus only reliable computational simulation can open up for detailed study and new insights [5, 6].

In spite of the maturity and popularity of numerical formulations, they are still characterized by a high computational cost and may lack of reliability and generality. In particular, major open challenges of computational multiphase flows include: (i) the discretization mesh for moving interfaces with fast dynamics cannot be easily built in a preprocessing, (ii) the high discontinuity in material properties that represent the interface must be found as a part of the solution, (iii) mass conservation, efficiency and robustness of the computations are difficult to achieve without dynamic adaptive methods and quantitative error estimation and finally, (iv) the capillary time step restriction condition is difficult to respect when treating explicitly the surface tension term in the Navier-Stokes equations [7].

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