

Numerical Simulation of 3D Bubbles Rising in Viscous Liquids using a Front Tracking Method

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Abstract

The rise of bubbles in viscous liquids is not only a very common process in many industrial applications, but also an important fundamental problem in fluid physics. An improved numerical algorithm based on the front tracking method, originally proposed by Tryggvason and his coworkers, has been validated against experiments over a wide range of intermediate Reynolds and Bond numbers using an axisymmetric model (Hua and Lou, *J. Comput. Phys.* **222**:769-795, 2007). In the current paper, this numerical algorithm is further extended to simulate 3D bubbles rising in viscous liquids with high Reynolds and Bond numbers and with large density and viscosity ratios representative of the common air-water two-phase flow system. To facilitate the 3D front tracking simulation, mesh adaptation is implemented for both the front mesh on the bubble surface and the background mesh. On the latter mesh, the governing Navier-Stokes equations for incompressible, Newtonian flow are solved in a moving reference frame attached to the rising bubble. Specifically, the equations are solved using a finite volume scheme based on the Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) algorithm, and it appears to be robust even for high Reynolds numbers and high density and viscosity ratios. The 3D bubble surface is tracked explicitly using an adaptive, unstructured triangular mesh. The numerical model is integrated with the software package PARAMESH, a block-based adaptive mesh refinement (AMR) tool developed for parallel computing. PARAMESH allows background mesh adaptation as well as the solution of the governing equations in parallel on a supercomputer. Further, Peskin distribution function is applied to interpolate the variable values between the front and

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the background meshes. Detailed sensitivity analysis about the numerical modeling algorithm has been performed. The current model has also been applied to simulate a number of cases of 3D gas bubbles rising in viscous liquids, e.g. air bubbles rising in water. Simulation results are compared with experimental observations both in aspect of terminal bubble shapes and terminal bubble velocities. In addition, we applied this model to simulate the interaction between two bubbles rising in a liquid, which illustrated the model's capability in predicting the interaction dynamics of rising bubbles.

Keywords: Computational fluid dynamics; Incompressible flow; Multiphase flow; Bubble rising; SIMPLE algorithm; Front tracking method; Adaptive mesh refinement; Moving reference frame