International Journal of Heat and Mass Transfer 103 (2016) 753–772

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

An improved interface preserving level set method for simulating three dimensional rising bubble

C.H. Yu [a], Z.T. Ye [a], Tony W.H. Sheu [b,c,d], Y.T. Lin [a], X.Z. Zhao [a,*]

[a] Ocean College, Zhejiang University, 866 Yuhangtang Road, Hangzhou, Zhejiang, People's Republic of China
[b] Department of Engineering Science and Ocean Engineering, National Taiwan University, No. 1, Section 4, Roosevelt Road, Taipei, Taiwan, Republic of China
[c] Institute of Mathematical and Applied Mathematics, National Taiwan University, Taiwan, Republic of China
[d] Center for Advanced Study on Theoretical Sciences (CASTS), National Taiwan University, Taiwan, Republic of China

A R T I C L E I N F O

Article history:
Received 27 March 2016
Received in revised form 22 July 2016
Accepted 25 July 2016

Keywords:
Interface preserving level set method
Bubble rising
Improved smoothed Heaviside function
Mass conservation term
Re-initialization equation
Surface tension force

A B S T R A C T

A new interface preserving level set method is developed in three steps to simulate bubble rising problems. In the first step of the solution algorithm, the level set function ϕ is advected by a pure advection equation. An intermediate step is performed to obtain new level set function through an improved smoothed Heaviside function. To keep the new level set function as a distance function and to conserve mass bounded by the interface, in the final solution step a mass correction term is added to the re-initialization equation. This two-phase numerical model is developed underlying the projection method to compute the incompressible Navier–Stokes solutions in collocated grids. In the discretizations of the level set advection equation and the re-initialization equation, the fifth-order weighted essentially non-oscillatory scheme is applied to prevent numerical oscillations occurring around discontinuous interface. The performance of the proposed level set method in conserving mass is compared with conventional level set method applied to solve the single bubble rising problem and the bubble bursting problem at a free surface. Merger of two bubbles is also investigated. Numerical results show that not only the surface tension force can be accurately calculated but also the mass can be conserved excellently using the present level set method.

1. Introduction

Bubble deformation, coalescence and breakup are widely encountered in science and in many industrial processes. Typical examples include propeller cavitation, heat and mass transfer between boiling liquid and bubbles, bubble formation resulting from underwater explosion and entrainment of wave breaking. Bubble motion in liquid fluids is strongly nonlinear, and the deformation of interface can be quite severe when flow is in motion. Therefore, numerical simulation of bubble motion becomes increasingly concerned by researchers of different disciplines. Investigation into bubble rising motion must take into account mass conservation and surface tension force, which play important roles and pose grand computational challenges [1]. In this study, attention will be addressed on the development of incompressible two-phase flow solver, which is applied to predict air/water interface accurately with the surface tension force being considered. Meanwhile, this algorithm can conserve mass as well in the prediction of interface movement.

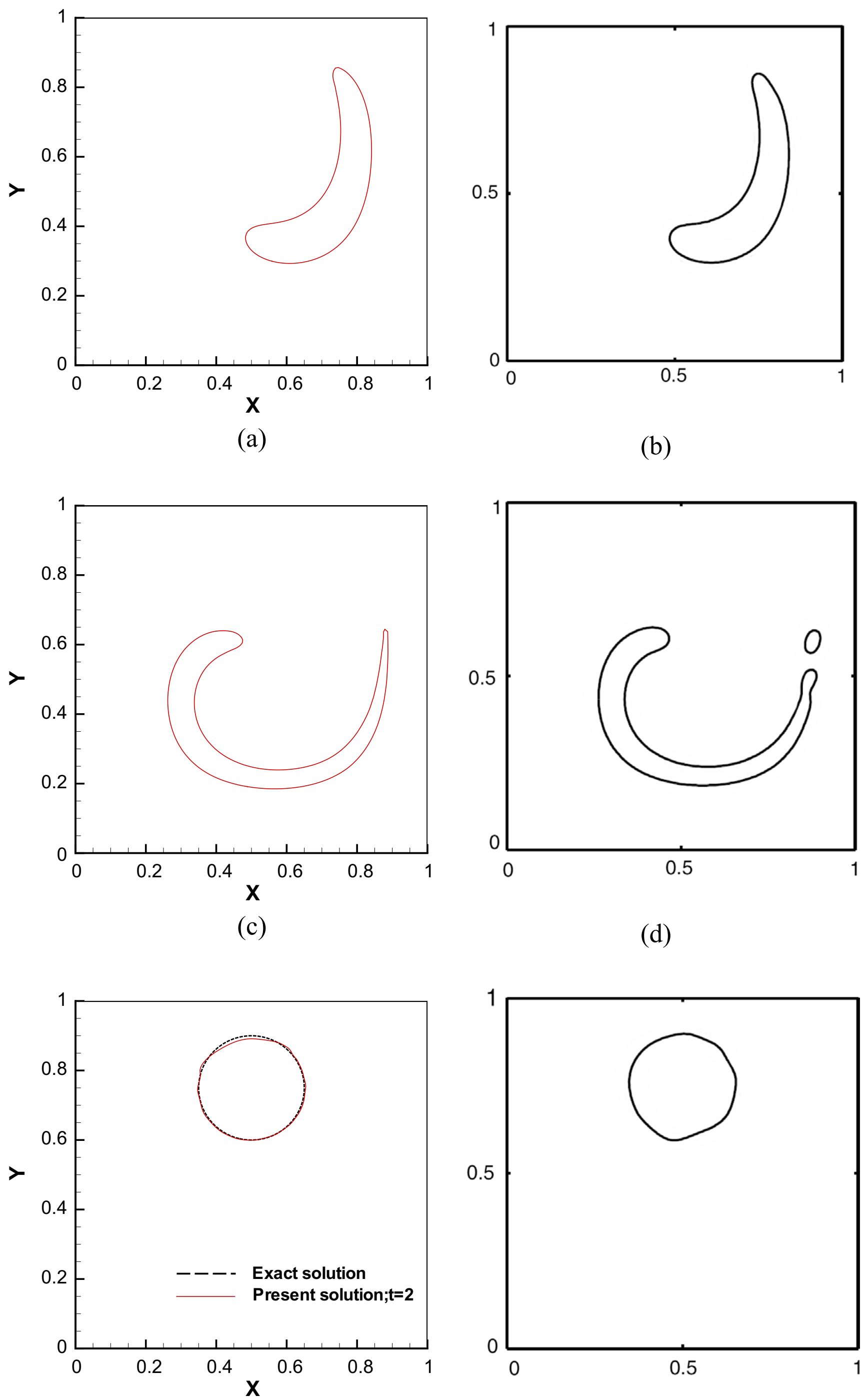
Interface tracking and interface capturing methods have been widely adopted to model two-phase flows [1]. The interface tracking method [2,3], implemented on a moving surface mesh, has been well known to be very effective in modeling a small interface deformation. However, the re-meshing procedure is computationally expensive when interface undergoes a significant deformation. Another major drawback of the interface tracking methods is that they have difficulty to model bubble coalescence and breakup. Therefore, it is computationally intensive and difficult to apply these methods to study bubble and droplet dynamics [4]. The interface capturing methods, such as the volume of fluid (VOF) methods and the level set (LS) methods, have been developed to simulate two-phase flows in a fixed grid since application of these methods can capture a greater topological change.

In the VOF method, the interface is defined in cells in which the magnitude of the volume fraction F is between zero and unity. The advantage of VOF method is its conservative nature. Hirt and Nichols [5] proposed an original VOF method, which belongs to the algebraic-type of VOF methods. They employed a donor–accep-

* Corresponding author. Fax: +86 571 88208890.
E-mail address: xizengzhao@zju.edu.cn (X.Z. Zhao).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.07.096
0017-9310/

tor formulation with flux limit manipulations to guarantee the boundedness of the numerical solution. Algebraic-type VOF methods always use high resolution schemes to compute volume fraction so that these approaches can normally render a highly diffusive interface and affect the accuracy of the solution. Different from algebraic-type VOF methods, the so-called geometrical-type VOF methods which add an extra step to identify the interface at new position (geometrical reconstruction) are developed. The widely used geometrical-type VOF method are the SLIC (Simple Line Interface Calculation) [6] and the PLIC (Piecewise Linear Interface Calculation) [7–9]. A PLIC scheme is more accurate than a SLIC scheme but it suffers a considerable algorithmic complexity. Another disadvantage of VOF method is that it is more difficult to calculate some geometric properties such as the unit normal vector, curvature and surface tension force along interface from the VOF function, which is defined as the fraction of the volume within each cell of fluids in a discontinuous fashion. An inaccurate calculation of these geometric properties can cause an imbalanced surface tension force to occur and it can furthermore lead to unphysical flow phenomena [10]. To reduce oscillatory and smear-



(a) (b) (c) (d) (e) (f)

Fig. 1. The predicted interfaces in 128 × 128 grids at. (a) $t = 0.5$; (b) $t = 0.5$ [23]; (c) $t = 1.0$; (d) $t = 1.0$ [23]; (e) $t = 2.0$; (f) $t = 2.0$ [23].