

NUMERICAL STUDY OF THE DYNAMIC COALESCENCE OF TWO AIR BUBBLES IN QUIESCENT COLUMN WATER

Jean-Michel Martinez*, Xavier Chesneau*, Belkacem Zeghmati*

* *Laboratoire de mathématiques et de physiques des systèmes - Groupe de mécanique et Energétique
MEPS-GME,
Université de Perpignan, 52 avenue Paul Alduy, 66860 Perpignan cedex*

Summary We present a new numerical method to calculate curvature and surface tension force in PLIC-VOF with the Continuum Surface Force (CSF). Based on staggered grid, this method is more accurate in determining surface tension contribution and therefore reduce moreover "spurious currents". We applied our method in the study of dynamics coalescence between two air bubbles. The results are presented as reconstructed interface with velocity field images.

Studies of two-phase flow are interesting for numerous applications ranging from environmental sciences to engineering. The presence of moving interface in two-phase flow is commonly approached with different numerical methods. The one, we used has been developed by Hirt and Nichols [1]. The VOF (Volume Of Fluid) method allows the knowledge of the liquid-vapor interface evolution by the use of a colour function commonly noted C or F which points out the volumic fraction of liquid ranging from 0 and 1. This method needs to solve a non diffusive transport equation, given by:

$$\frac{\partial F}{\partial t} + \vec{\nabla} \cdot (\vec{V} F) = 0 \quad (1)$$

in which F represents the colour function and \vec{V} the velocity field. The resolution of this equation is based on geometrical hypothesis which ensures the interface's integrity. The PLIC-VOF (Piecewise Linear Interface Construction - Volume of Fluid) method reconstructs the interface by a segment of straight line contained within each computational cell. This method is more accurate, less diffusive and allows a more important mass conservation. In order to include surface tension force in the Navier-Stokes's equations, several models have been developed, amongst which Brackbill et al.'s is the most commonly used [2]. This model transforms surface force into volumic force by using Dirac peak centered on the interface. The force thus being described (Continuum surface force-CSF) is expressed by the following relation:

$$\vec{F}_{sv} = \sigma \kappa \delta_s \vec{n} \quad (2)$$

in which σ represents superficial tension, δ_s Dirac peak centered on the interface, \vec{n} the interface normal vectors and κ the curvature giving:

$$\kappa = -\vec{\nabla}_s \cdot \vec{n} \quad (3)$$

in which $\vec{\nabla}_s \cdot \vec{n}$ represents the surface divergence of the normals for an interface surface element. The normal vectors is determined by the normalised gradient of the colour function F. A smoothed colour function by convolution with a β -spline kernel is commonly used to increase the numerical accuracy of the normal and of the curvature.

In order to optimise numerical calculation on the evaluation of surface tension's contribution without using a smoothed colour function by CSF, we have developed a new technique calculation for curvature and superficial tension force. This method leads to reduce drastically the presence of "spurious current" which developping at the interface and allows to use the surface tension contribution with more accuracy.

The method we worked out uses the direct definition of two dimensionnal surface divergence and does not need smoothed colour function to improve accuracy.

$$k = \left| \frac{\partial \vec{n}}{\partial S} \right| \quad (4)$$

in which S is the length along the curves which represent the interface.

The normal vector is calculated on each face and at the corners of a MAC cell. The positioning of the segment within the cell leads the choice of the normal vector which are the nearest from the intersection point between the cell and the segment. The length ∂S is approximated by an average of all the segments presented in the main cell since each staggered cell produce its own segment. The calculus is then renewed for each cell on the entire domain with the same assumptions. Once calculated the curvature, the superficial tension force is deduced from equation 2, which is included in the Navier Stokes equations as an external forces field. The latters are discretised on MAC grid, which is defined as a control volume and the projection algorithm is used for solving the Navier-Stokes equations. Therefore the superficial tension force have to be included on face of each computationnal cell. This contribution is numerically defined on a staggered cell. Obviously, our method allows to calculate curvature on center of each cell. Consequently colour function values F are determined on staggered cell with geometrical assumptions, which allow to define the curvature on the face of the main cell and this technique is applied on each face of the volume control. The validation tests show that our method is more

accurate than those previously implemented [3, 4] and leads to less "spurious currents".

This method were applied on two air bubble coalescence in quiescent column water, with temperature ranging from 20° to 80° , different radius size and different Bond and Reynolds number. Results presented concern the reconstructed interface with velocity field for four different time step iteration ranging from 1 to 300 at 20° temperature with radius $R_0 = 1$ mm and initial time step $\Delta t = 0.05$ ms.

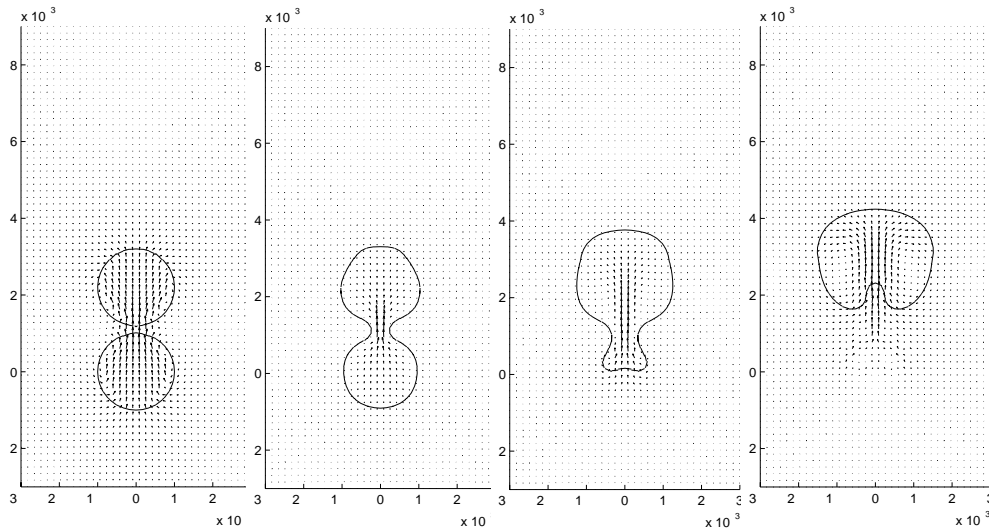


Figure 1. Coalescence between two bubbles

The sequence reported on figure 1 proves the potentiality of our method. The modelisation thus deduce on coalescence reveals several important parameters as the distance between each bubble, the radius and the time step Δt . Further results show a real dependance from surface tension with Bond number, and also temperature. This parameters leads to different deformations and sometimes breakup of bubbles before the coalescence.

CONCLUSION

We developed a new method based on staggered grid for calculating curvature and surface tension force of which the results present better agreement with reality. The surface tension force is included in the Navier-Stokes equations which are solved numerically with projection method. We applied this resolution on the coalescence between two air bubble in quiescent water at constant temperature and we characterised different parameter, which induce the deformation or the breakup of bubbles before coalescence. We implemented different case of coalescence which lead to find correlation between size, surface tension, and the distance which separate each bubble.

References

- [1] Hirt C.W., Nichols B.D., Volume of fluid (VOF) Method for the dynamics of free boundaries, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, (1979).
- [2] Brackbill J.U., Kothe D., Zemach C., A continuum method for modeling surface tension, Theoretical division, Los Alamos National Laboratory, Los Alamos, New Mexico, (1991).
- [3] Meier M., Yadigaroglu G., Smith B.L., A novel technique for including surface tension in PLIC-VOF methods, *Eur.J.Mech.B/Fluids* **21**, pp 61-73, (2002).
- [4] Zaleski S., Computation of multiphase flow by volume of fluid and high-order front tracking methods, Rapport d'activité de modélisation en mécanique, Université Pierre et Marie Curie, Paris VI.