Simulation of the Coalescence of two Bubbles Rising in a Vertical Pipe with VOF Interface Tracking Method

Article · April 2007

DOI: 10.1063/1.2729702

4 authors, including:

Djemai Merrouche

Kamal Mohammedi
University M'Hamed Bougara of Boumerdes

Idir Belaidi
University M'Hamed Bougara of Boumerdes

Simulation of the Coalescence of two Bubbles Rising in a Vertical Pipe with VOF Interface Tracking Method

Djemai Merrouche[(1)], Kamal Mohammedi[(2)], Idir Belaidi [(2)] and Bachir Mabrouki [(2)]

(1) CRNB,COMENA Ain-Ouessara 17000 Djelfa, Algeria
(2) Groupe Modélisation en Mécanique et Productique/ LMMC
M. Bougara University, Boumerdès 35000 Algeria

Abstract. In this paper, we report the computational results of the coalescence of two bubbles rising in a liquid at rest. The calculations where conducted in parallel using the open source code OpenFOAM. The equations of motion where solved using the finite volume method and the interface is advected using the volume of fluid method (VOF). The predicted behavior of two bubbles coalescence is in reasonable agreement with experimental and numerical results obtained by other authors.

Keywords: Bubbles, VOF method, Coalescence, Interface Capturing.
PACS: 47.55.D, 47.55.df,

INTRODUCTION

The knowledge of two-phase flows behaviour is of great interest in various processes ranging from engineering applications to environmental phenomena. The study of bubbles coalescence and break-up phenomena occurring in such flows is very important because of their influence on the bubble size distribution.

Numerous techniques for tracking the interface have been developed, each with its own strengths and weaknesses. The most widely used classes of methods are Eulerian and mixed Eulerian-Lagrangian methods. The dynamic and deformation of the liquid-air interface is commonly analysed by Volume of Fluid (VOF) methods. These methods are commonly used for two-phase flow simulations and ensure good agreement between numerical and experimental data.

Many studies were conducted on bubble coalescence under stagnant conditions. In the present paper, we attempt to model the behavior and interaction of two bubbles during their rise in the liquid column using the interFoam solver of the OpenFoam code. This method was applied on two air bubble coalescence in quiescent column water with different Morton and Eötvös number. Results presented concern the reconstructed interface with velocity field for four different time step iteration.

MODELLING

Let us consider two spherical air-bubbles rising through quiescent fluid in a column. The fluid and the gas are assumed to be incompressible. The initial shape is defined spherical for both of the bubbles. The interface motion is computed by solving the advection equation. The mathematical model describes the simultaneous flow of two immiscible, incompressible fluids, each having a constant viscosity and including surface tension. It contains a single set of conservation equations for the whole flow field even though material properties are discontinuous across the fluid boundaries. The mass continuity and momentum equations are given by the following expressions:

$$\nabla . U = 0 \tag{1}$$

$$\frac{\partial \rho U}{\partial t} + \nabla .(\rho U U) = -\nabla p + \rho g + \nabla . \tau + \int_{S(t)} \sigma \kappa' n' \delta(x - x') dS \tag{2}$$

where U is the velocity, p the pressure, g the gravity, ρ the density, σ is the surface tension coefficient, κ the curvature of the liquid interface, τ is the Newtonian viscous stress and n represents a unit vector normal to the interface.

The last term of the equation (2) represents the source of momentum due to surface tension which is modelled by the continuum surface tension force (CSF) developed by Brackbill et al., 1992. The surface force is transformed into volumetric force by using a delta Dirac function $\delta(\ )$ centred on the interface S. The interface between the phases is simultaneously computed using an interface capturing methodology which employs the volume fraction of the fluid γ as an indicator function. This fluid volume fraction is defined as:

$$\gamma = \begin{cases} 1 & \text{for a point inside the fluid} \\ 0 \prec \gamma \prec 1 & \text{for a point in the transitional region} \\ 0 & \text{for a point inside the gas phase} \end{cases}$$

The indicator function associated with a particular fluid is advected with it as a Lagrangian invariant which obeys a transport equation of the form:

$$\frac{\partial \gamma}{\partial t} + \nabla .(U \gamma) = 0 \tag{3}$$

The density and viscosity properties are then deduced from the following expressions:

$$\rho = \gamma \rho_f + (1 - \gamma) \rho_g \tag{4}$$

$$\mu = \gamma \mu_f + (1 - \gamma) \mu_g \tag{5}$$

where the subscripts f and g indicate fluid and gas phases respectively.

The surface tension force is expressed by the following relation:

$$\int_{S(t)} \sigma \kappa' n' \delta(x - x') dS \approx \sigma \kappa \nabla \gamma \tag{7}$$

where the curvature of the interface is given by $\kappa = \nabla.\left(\frac{\nabla \gamma}{|\nabla \gamma|}\right)$

In the Weller Scheme [5], the compression of the interface is not obtained by using a compressive differencing scheme, but rather by introducing an artificial compression term into the indicator function equation:

$$\frac{\partial \gamma}{\partial t} + \nabla.(U_{\gamma}) + \nabla.(U_r.\gamma(1-\gamma)) = 0 \quad (8)$$

where, U_r is a velocity field needed to compress the interface.

The artificial term is only active in the thin interface region. There are many possible ways to formulate the compression velocity U_r. The actual version of InterFOAM uses the interface compression technique by introducing a relative velocity term in the advection equation. There is no smoothing function for the volume fraction.

RESULTS

The simulations were conducted for 3 cases: co-axial, off axis and adjacent rising bubbles. We considered a rectangular domain with the two initially circular bubbles inside. A zero velocity field is given at the initial time. The boundary prescribed conditions are given as follows: on the box bottom: "no-slip" condition; on the walls, "free-slip" condition. On the upper boundary of the box, "outflow" condition.

TABLE 1. physical and numerical data used in the simulations

CASE	1	2	3
Bubble diameter d	0.01m	0.01m	0.01m
Dimensionless number	Re = 2 $E_0 = 1.2$	Re = 50 $E_0 = 20$	Re = 50 $E_0 = 20$
Distance from bottom	d	d	d
Distance (h) between bubbles	1.15d	1.15d	1.15d
ρ_1/ρ_2	100	100	100
μ_1/μ_2	100	100	100
Domain size	0.04 x 0.08 m	0.04 x 0.08 m	0.04 x 0.08 m
Cells Number	100 x 200	100 x 200	100 x 200

We investigate the influence of neighboring bubbles on the shapes dynamics and collective behavior of the rising bubbles. The time step is: 1e-5. The physical properties that were used in these simulations are listed in table1.

In order to check that coalescence and break up of bubbles did not occur as a result of numerical errors, we study the simulation of two axis bubbles in the spherical regime. If the two bubbles remain spherical for a long time of simulation before interaction, we can decide that our simulations will be conducted without errors. The case1 represents this state and we observe a good coalescence in this regime.

Generally, when a single bubble rises due to the buoyancy forces, the pressure at the lower surface of the bubble is higher than that at the top surface of the bubble. A vortex sheet developed at the surface of the bubble has a sense of rotation which induces a tongue of liquid pushing the bubble from below. Deformation occurs when rising bubbles shape becomes ellipsoidal due to a pressure difference between the top and bottom surfaces of the bubbles. The liquid jet formed behind the leading bubble induces a deformation of the trailing bubble. Once the bubbles are getting closer, the trailing bubble accelerates and touches the leading one. The surface tension force decreases inducing a further fragmentation.

co-axial rising bubbles

From figures of velocities before coalescence, we can see the effect of the wake of the leading bubble on the shape of the trailing bubble. The base of the trailing bubble is severely indented owing to the greater velocity of the liquid behind the trailing bubble compared to the velocity of the liquid preceding that bubble. In figure 4, the base of the leading bubble deforms inward, due to interaction with the trailing bubble and the liquid immediately behind the leading bubble.

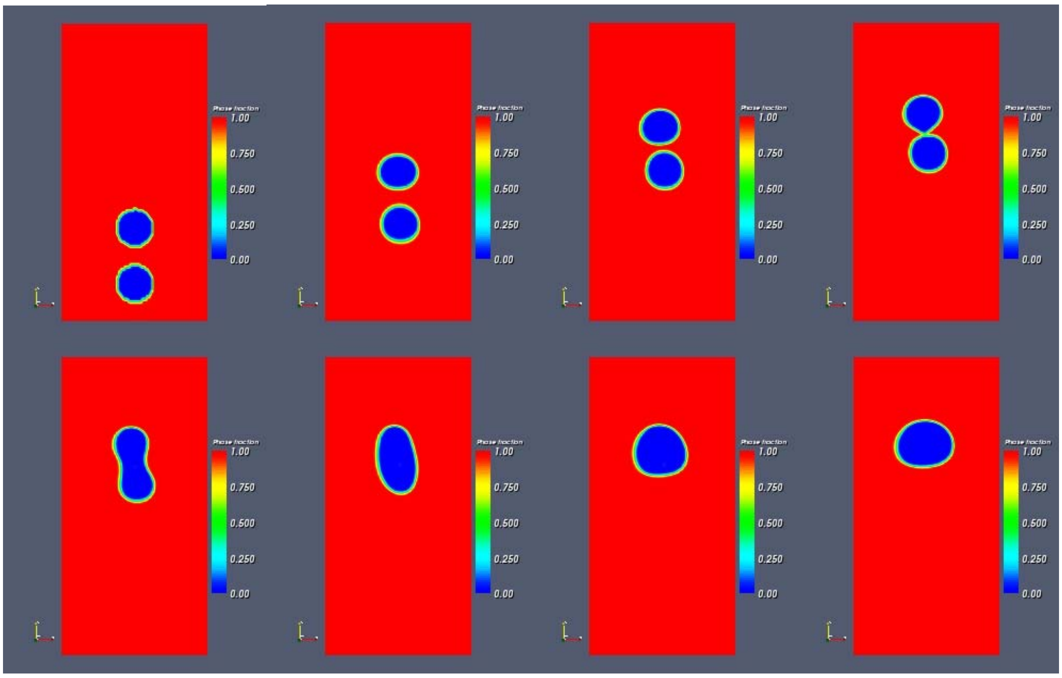

FIGURE 1. Case 1: axial coalescence of two bubbles

Two bubbles with the same diameter “d” are initially at rest and aligned on the center line of the computational domain. The initial distance between the bubbles is “h”. In the case2, the figures show the evolution of the two bubbles in time. The first bubble develops to its normal shape as it was alone in the domain. The last bubble is deformed under the influence of the vortices behind the first bubble. Accompanying the deformation the tailing bubble accelerates and coalesces with the leading bubble.

Good qualitative agreement is found with the results presented in [1,2,3]. The figure 2 shows that the first bubble acquires a spherical cap shape before coalescence which is consistent with observations of authors in [1].

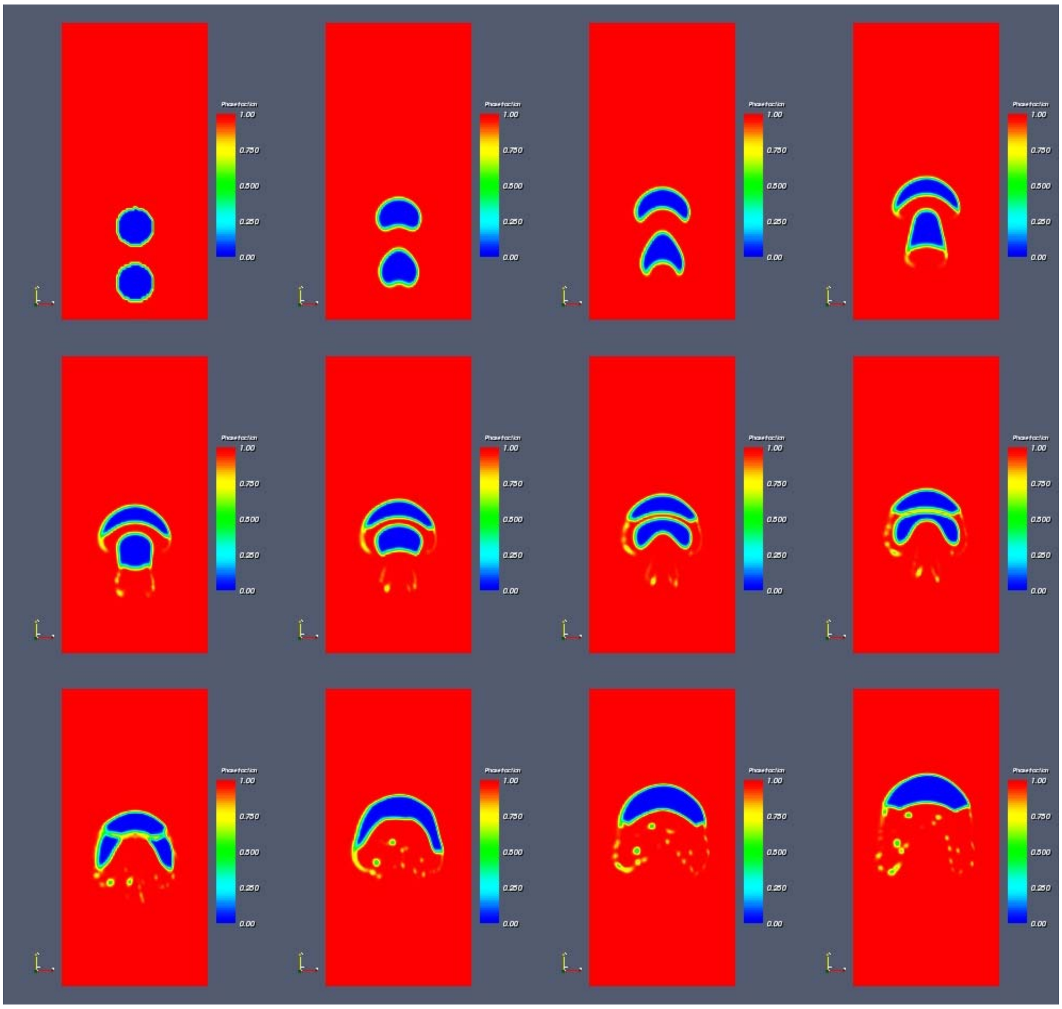

FIGURE 2. Case 2: axial coalescence of two bubbles

Off axis rising bubbles

The bubbles are initially misaligned. The physical and numerical data related to this case are also reported in table1. The results are described in case3. The final figure shows the non-asymmetric nature of the problem.

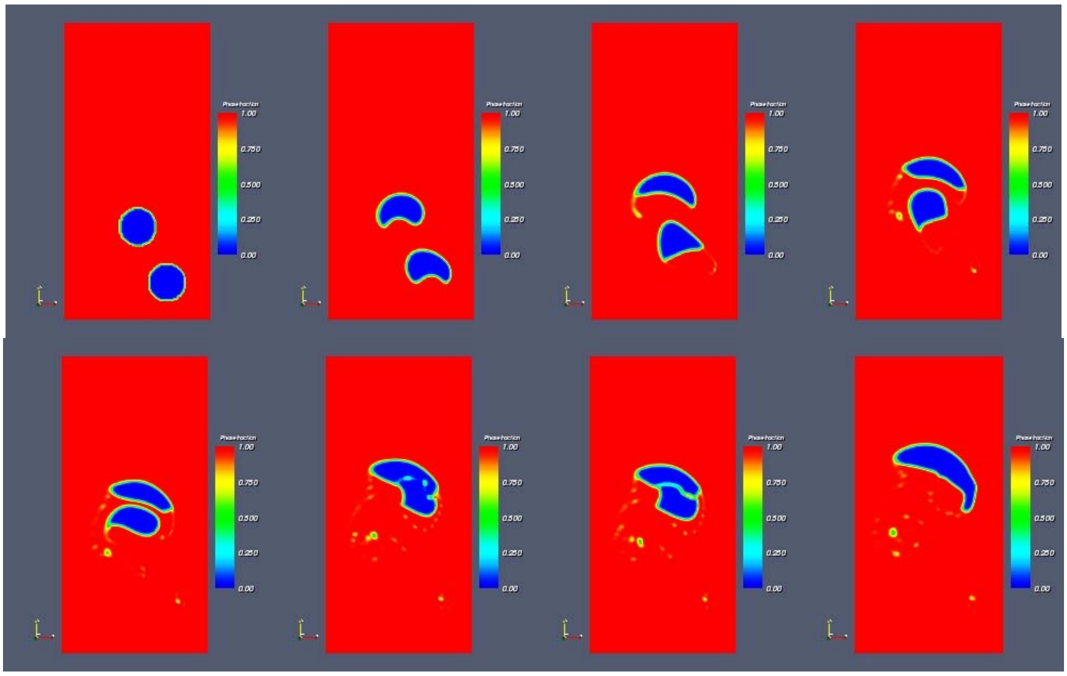

FIGURE 3. Case 3: coalescence of two Off-Axis rising bubbles

CONCLUSION

The dynamics of bubble coalescence in a quiescent liquid has been studied using a robust numerical model. With the parallel version of the solver it is shown that the predicted behavior of bubble coalescence is in reasonable agreement with other research works. In the future, we will attempt to include the effect of turbulence in the coalescence.

ACKNOWLEDGMENTS

Thanks to CERFACS for the PALM software Licence.

REFERENCES

1. Ler Verkrijging Van, Path and weak of a rising bubble, Doctoral Thesis, 2001.
2. J.M. Martinez & al., Numerical study of the dynamic coalescence of two air bubbles in quiescent column water, XXI ICTAM, Warsaw, Poland, 15-21 August 2004.
3. A. Lucic and al., Numerical simulation and experimental studies of the fluid dynamic behaviour of rising bubbles in stagnant and flowing liquids, Technische Universität München, 2000.
4. Lichen Yuguo Li and Richard Manasseh, The coalescence of bubbles –a numerical study, Third International Conference on Multiphase Flow, ICMF'98, France.
5. Henrik Rusche, Computational Fluid Dynamics of Dispersed Two-Phase Flows at High Phase Fractions, Imperial College of London, PhD thesis, 2002.
6. R. Singh , W. Shyy, Three-dimensional adaptive grid computation with conservative, marker-based tracking for interfacial fluid dynamics, AIAA 2006-1523
7. L.Yuguo Li , Richard Manassch, The coalescence of bubbles- A numerical study, Third international Conference on Multiphase Flow, ICMF'98