A Study on the Flow with Interfacial Phenomena Using VOF Method

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Abstract: A numerical method for simulating free surface flows including the surface tension is presented. Numerical scheme is based on a fractional-step method with a finite volume formulation and the interface between liquid and gas is tracked by Volume of Fluid (VOF) method. Piecewise Linear Interface Calculation (PLIC) method is used to reconstruct the interface and the surface tension is considered using a Continuum Surface Force (CSF) model. Several free surface flow phenomena were simulated to show its effectiveness to find such phenomena.

Keywords: Free surface, Volume of Fluid method, Surface tension, Cotinuum surface force model,

1. INTRODUCTION

Flow phenomena with free surfaces can be frequently found in the nature and become an important field of study in both sience and industrial aspects . In the numerical method to solve these phenomena there are two categories: i)surface fitting methods in which numerical grid system are modified according to the variation of the surface. ii) surface caturing method in which a fixed grid system are utilized.

Surface capturring method which is presently used has merits of no need to reconstruct mesh at each time and capable of treating a flow with high-gradient surface movement. In this method, VOF(Volume of Fluid) method[1] ,MAC(Marker and Cell) method[2] and LS(Level Set) method[3]. LS method has a defect of not meeting the conservation of mass, but merits of obtaining an exact curvature necessary to get surface tension.

On the otherhand, VOF method has merits of good mass conservation but difficulty to get curvature at the interface. Later CLSVOF(Coupled Level Set and Volume of Fluid) method[4] was developed so as to combine both merits of VOF and LS method.

2. NUMERICAL METHOD

VOF method is used for free surface tracking, in which, each phase is identified by using volume fraction. The volume fraction and the volume evolution equation are defined as following equations.

$$f=V_{fluid}/V_{cell} \qquad (6)$$

$$\frac{\partial f}{\partial t}+\nabla\cdot(u_c f)=0 \qquad (7)$$

In this paper, two working fluids are specified as air and water, assumed as incompressible and insoluble. The Navier-stokes equations are

$$\nabla\cdot u_c=0 \qquad (8)$$

$$\rho[\frac{\partial \mathbf{u}_c}{\partial t}+\nabla\cdot(\mathbf{u}_c\mathbf{u}_c)]=-\nabla p+\nabla\cdot\mu\nabla\mathbf{u}_c+\mathbf{s} \qquad (9)$$

where $\mathbf{u}_c$ is the fluid velocity, p is the pressure. Governing equations are solved by using fractional step method on the cell centered grid. And time marching scheme for convection term is Adams-Bashforth method and, for viscous term, Crank-Nicolson method is applied. CSF(Continuum Surface Force) model[5] is used for the application of surface tension, where the surface tension is represented as a volumetric force in the source term of the Navier-Stokes equation.

In the CSF model[5], a smoothed volume fraction is needed to obtain accurate unit normal vector and the curvature at the interface, in which Peskin Kernel[6] is used to obtain smoothed volume fraction.

3. NUMERICAL RESUL

In this investigation, a few representative experimental results were numerically analyzed. Some of them will be presented in the following.

3.1 Merging of two gas bubbles

Merging of two gas bubbles rising with buoyancy is simulated. Two bubbles have the same size and boundary condition are the same with the simulation of Sussman and Puckett[4]. The density and viscosity ratio of two working fluids is 1/20 and 1/26, respectively. Dimensinless numbers of $Re=\rho_l LU/\mu_l=50^{3/4}$, $We=\rho_l U^2 L/\sigma=50$, $Fr=U^2/gL=1$ are used, where $U=\sqrt{gL}$, and characteristic length L is the initial radius of bubble. Fig.1 is the numerical results and Fig.2 the numerical results of Sussman and Puckett[4] using CLSVOF method. Our numerical results show a good agreement with the numerical results of Sussman and Puckett[4] .

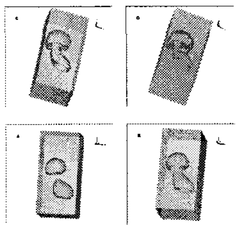


Fig.1 Evolutions of merging of two gas bubbles at (A) t=1.2, (B) t=2.0, (C) t=2.7, (D) t=2.9 (sec).

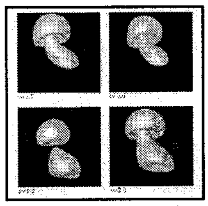
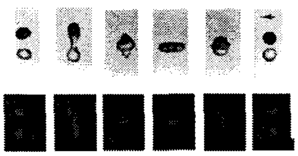


Fig.2 Evolutions of merging of two gas bubbles. Reprinted from [4].

3.2 Collision behavior of water droplets

Very complex flow phenomena appear after two droplets collide each other. Droplet collision behavior is normally divided into four categories; bouncing, coalescence, stretching separation and reflexive separation. We performed a series of numerical simulations on the droplet collision for various conditions of Weber number, impact parameter and droplet size-ratio, and compared the results with some experimental results and other theoretical predictions.

Fig.3 show results of reflexive separation. While Fig.3(a) is the experimental results of Ashgriz and Poo[7], Fig.3(b) is numerical ones. There could be some time lag between the experiments and the numerical results respectively, but in generally, numerical results agree well with experiments. Fig.4 shows various theoretical predictions dividing the regions of coalescence, reflexive separation and stretching separation at the condition of droplet size ratio of 0.75. While a solid and dashed lines are the theoretical prediction of Ashgriz and Poo[7], Brazier-Smith et al[8], Park[9] and Arkhpov et al[10] , the discretized marks indicate numerical results. While Ashgriz and Poo[7] and Brazier-Smith et al[8] derive theoretical prediction using the assumption that the combined mass at any phase of the collision process can be transformed into a nominal spherical droplet, Park[9] and Arkhipov et al[10] derived theoretical prediction using the energy equations of the volume in the interaction region. Our numerical results shows good agreement with theoretical prediction of Ashgriz and Poo[7] and Brazier-Smith et al[8].



a

b

Fig.3 Reflexive separation with no satellite for $\Delta = 1$, $We = 23$ and $x = 0.05$ (a : experimental results[9], b : numerical results)

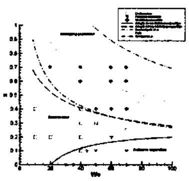


Fig.4. Comparisons of the numerical results with the analytic ones (droplet size ratio of 0.75)

4. SUMMARY

In this study, the Navier-Stokes solver-code with the VOF method and CSF model has been developed to analyze the three-dimensional unsteady incompressible viscous with free surface. Peskin kernel[7,8] is used to obtain smoothed volume fraction for accurate surface tension. And sevreal Several free surface flow phenomena were simulated to show the effectiveness of the scheme.

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