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Two-dimensional bubble rising through quiescent and non-quiescent fluid: Influence on heat transfer and flow behavior

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ABSTRACT

An understanding of the bubble properties, size distributions and shapes and their ability in various applications is of fundamental importance for comprehending flow dynamics and mass transfer phenomena in bubble column reactors. A large number of studies have focused on open tube bubble columns, and the knowledge concerning bubble columns is still limited. In this paper, a 2D phase field model is presented for numerical study of a bubble rising in a fluid and its influence on heat transfer parameters on a single channel. The computational model entails the Navier–Stokes equation for fluid flow and VOF(Volume of fluid) model for interface deformation and morphology. A C++ based open source software; OpenFOAM is utilized for this simulation. It is found that rising bubble can be used as an effective method for reducing thermal boundary layer and increasing Nusselt number and consequently increasing heat transfer in industrial applications. Investigating the influence of the bubble rising on the non-quiescent fluid in a vertical channel revealed that bubble rising in high Reynolds number does not have sensible effect on Nusselt number, but in low Reynolds number it show a significant enhancement in Nusselt number. Also the results predicted that bubble injection frequency has a direct effect on Nusselt number behavior.

1. Introduction

Multi-phase fluid systems play an important role in many natural and industrial processes such as combustion, petroleum refining, chemical engineering and cleaning. Rising of a bubble in a liquid is one of the typical dynamics of multi-fluid systems. A sound understanding of the fundamentals of the rising bubble is crucial in a variety of practical applications ranging from the rise of steam in boiler tubes to gas bubbles in oil wells. Numerical modeling of a rising bubble in a fluid medium can be rather difficult because of the singularity-like discontinuity of fluid properties such as density and viscosity, and of the pressure jump across the interface due to surface tension. Useful computational schemes have been developed to overcome the difficulties; some popular approaches include the volume of fluid [1], level set, phase field and front tracking [2]. Chen et al. [3] and Maxworthy [4] for vapor bubbles moving under a submerged surface in water, they concluded that bubble velocity increases with bubble volume and plate angle, reaching a maximum at an angle of 50° to the horizontal. In a study by Brucker [5], PIV (Particle Image Velocimetry) was used to obtain the temporal evolution of the flow field in the near wake of single rising bubbles of 5–7 mm diameter in water. Shin and Choi [6] proposed the efficient and stable way of sharp energy method for two-phase flow with phase. They simulated a bubble rise with phase change and compared with experimental data. The bubble growth rate from the simulation was well compared with experiment. Liu and Palm [7] investigated a three dimensional numerical study on bubble growth and merger in a micro-channel with diameter of 0.64 mm with R134a as working fluid. They found that the evaporation rate is much higher in the first two stages due to the thermal boundary layer effects. Dhole et al. [8] studied Mass transfer from a spherical bubble rising in power-law fluids at intermediate Reynolds numbers. Based on their presented numerical results, a simple mass transfer correlation was developed to estimate the value of Sherwood number in a new application. The dynamics of a vapor bubble between its liquid phase and a heated plate studied in relation to the breakdown and recovery of the film boiling by Joo and Park [9]. They focused on the effects of the degree of superheat from the solid plate, and the wetting/dewetting characteristics of the liquid on the solid plate. Zhang et al. [10] studied an SPH modeling of bubble rising and coalescing in three dimensions. Several cases of single bubbles rising through viscous fluids are tested and the SPH results validated by both the experimental data and other numerical results. Furthermore, the phenomena of bubbles coalescing in both vertical and horizontal directions simulated. The flow and heat transfer of MHD nanofluid between parallel plates in the presence of thermal radiation

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Nomenclature

Cp_g(J/kg.K)	Gas heat capacity
ρ (kg/m^3)	Liquid density
Cp(J/kg.K)	Liquid heat capacity
$\hat{\rho}$ (kg/m^3)	Gas density
K(W/m.K)	Liquid heat conductivity
ρ_b (kg/m^3)	Bulk density
K_g(W/m.K)	Gas heat conductivity
ν_t (m^2/s)	Turbulant Kinitic Viscosity
L(m)	Duct height
$\hat{\nu}$ (m^2/s)	Gas Kinitic Viscosity
P(Pa)	Pressure
ν_l(m^2/s)	Liquid Kinitic Viscosity
F_s(N)	surface tension force
μ_l(Kg.m/s)	Liquid Dynamic Viscosity
T_{in}(K)	Initial gas and liquid temperature
$\hat{\mu}$(Kg.m/s)	Gas Dynamic viscosity
T_{hot}(K)	Hot wall temperature
μ_b(Kg.m/s)	Bulk Dynamic viscosity
t(s)	Simulation time step
λ_l	Liquid Phase Conductivity
U(m/s)	Velocity
$\hat{\lambda}$	*Gas Phase Conductivity*
W(m)	Duct width
λ_b	Local Average Conductivity

Greek symbols

α	Volume Fraction
τ(N/m)	Surface Tension

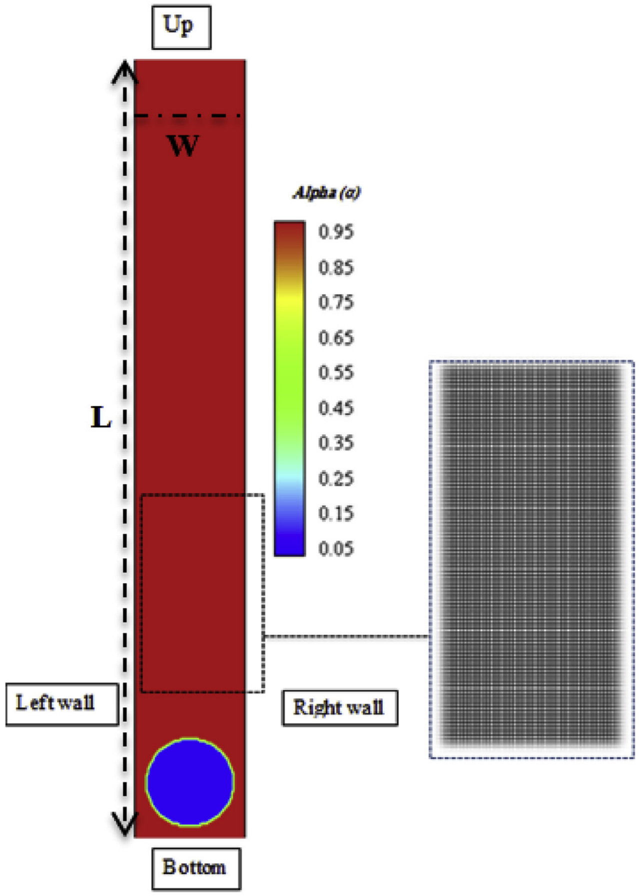

Fig. 1. Geometry of the problem.

Table 1
Simulation parameters quantities.

Parameter	Description	Value
Properties		
t(s)	Simulation time step	0.00005
ν_l (m^2/s)	liquid dynamic viscosity	1×10^{-4}
ρ (kg/m^3)	Liquid density	1000
Cp(J/kg.K)	Liquid heat capacity	1000
K(W/m.K)	Liquid heat conductivity	10
ν_g (m^2/s)	Gas dynamic viscosity	1×10^{-4}
ρ_g (kg/m^3)	Gas density	10
Cp_g (J/kg.K)	Gas heat capacity	1000
K_g (W/m.K)	Gas heat conductivity	0.025
τ(N/m)	Surface tension	0.1
T_{in}(K)	Initial gas and liquid temperature	293
T_{hot}(K)	Hot wall temperature	393

Table 2
First case boundary layers which is considered in this study (quiescent liquid).

quiescent liquid case	
geometry parts	Boundary condition
Bottom	Wall
up	Wall
Right and left walls	Wall (Constant Temperature)

Table 3
Boundary conditions for the second case, bubble rising in a non-quiescent liquid.

non-quiescent liquid case	
geometry parts	Boundary condition
Bottom	Velocity inlet
up	Pressure outlet
Right and left wall	Wall (Constant temperature)

was studied by Dogonchi et al. [11]. The effects of various parameters such as the squeeze number, the magnetic parameter, the volume fraction of nanofluid, the Eckert number and the radiation parameter investigated on the velocity and temperature in their study. Observations of coalescence between different size bubbles during pool nucleate boiling of water on a horizontal, electrically-heated titanium foil by Golobic at al [12]. revealed evidence of asymmetrical interactions between the bubbles before coalescence. They suggested that a fast growing bubble could push superheated liquid under a more slowly growing bubble. Bubble coalescence was also experimentally studied by Coulibaly et al. [13] who showed that the heat transfer was enhanced only when the coalescence occurred at least 2 ms after bubble