UNIVERSITI MALAYA

ORIGINAL LITERARY WORK DECLARATION

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Registration/Matric No: **KGA110080**

Name of Degree: **Master of Engineering Science**

Title of Project Paper/ Research Report/ Dissertation/ Thesis (“this Work”):

‘CFD study of formation and rise characteristics of a single bubble in bubble column’

Field of Study: **Multiphase flow**

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ABSTRACT

The volume of fluid with the continuum surface force (VOF-CSF) method has been used in the current numerical work to investigate the bubble formation and the bubble shape in a bubble column. The shape of the bubble has been tracked by using the piecewise linear interface calculation (PLIC). The effect of orifice sizes ranging from 0.5 mm to 1.5 mm on the bubble formation stages (i.e., expansion, elongation and pinch off), bubble contact angle, departure diameter, time and shape of bubble was investigated under a constant inlet velocity (0.2 m/s) boundary condition. It was found that a leading bubble required a longer time to detach from an orifice in comparison to the following bubbles, but interestingly the third bubble took quite longer time than the second bubbles. This model has also been used to study the effect of Bond number and Reynolds number on bubble formation. The velocity field around the bubble has a significant effect on bubble formation, when the Bond number and Reynolds numbers are changed. Moreover, the effect of trapezoidal type columns to the rise velocity of a single bubble was simulated using a couple level set volume of fluid (CLSVOF) method. The bubble rise velocity reduced with the increase of trapezoidal angle or with the decrease of the top column width. Subsequently, the bubble rising distance for a given particular total time reduced with the increase of the trapezoidal angle. The trapezoidal cavity enhanced the spatial or lateral distribution of a bubble to left and right of the column. The trapezoidal column also enhanced the change of bubble shape from elliptic to circle and vice versa with the increase of the time or the vertical height. Finally, the VOF-CSF method was applied to investigate the effect of non-dimensional liquid viscosity and the effect of non-dimensional surface tension coefficient on co-axial and parallel bubble coalescence as well as rise trajectories in stagnant liquid. It was found that the coalescence time of two co-axial bubbles decreased with the reducing surface tension coefficient and reducing liquid viscosity. For the parallel bubbles coalescence, non-dimensional critical flat gap of bubble coalescence (Sc) decreased with the increase of bubble diameter under reduction of surface tension coefficient. But Sc increased with reduction of liquid viscosity. When the initial flat gaps of bubble are larger from Sc; the parallel bubbles enchanted by its repulsive effect. The findings from these works may be able to provide a fundamental knowledge and also be useful for designing a sparger for bubble column reactors.

ABSTRAK

Isipadu cecair dengan kekerasan permukaan kontinum (VOF-CSF) kaedah telah digunakan dalam kerja-kerja berangka semasa untuk menyiasat pembentukan gelembung dan bentuk gelembung dalam lajur gelembung. Bentuk gelembung telah dikesan dengan menggunakan pengiraan muka piecewise linear (PLIC). Kesan saiz lubang antara 0.5 mm hingga 1.5 mm pada peringkat pembentukan gelembung (iaitu, pengembangan, pemanjangan dan picit off), sudut sentuh gelembung, diameter berlepas, masa dan bentuk gelembung telah disiasat di bawah halaju masuk malar (0.2 m/s) keadaan sempadan. Ia telah mendapati bahawa gelembung terkemuka diperlukan masa yang lebih lama untuk menanggalkan daripada orifis berbanding dengan buih berikut, tetapi menarik gelembung ketiga mengambil masa agak lama daripada buih kedua. Model ini juga telah digunakan untuk mengkaji kesan jumlah Bon dan nombor Reynolds pada pembentukan gelembung. Bidang halaju sekitar gelembung mempunyai kesan yang besar ke atas pembentukan gelembung, apabila bilangan Bon dan nombor Reynolds diubah. Selain itu, kesan ruangan Jenis trapezoid dengan halaju kenaikan gelembung tunggal telah disimulasi menggunakan menetapkan kelantangan beberapa tahap cecair (CLSVOF) kaedah. Halaju kenaikan gelembung dikurangkan dengan peningkatan sudut trapezoid atau dengan penurunan sebanyak lajur lebar atas. Selepas itu, jarak gelembung yang semakin meningkat untuk jumlah masa tertentu yang diberikan dikurangkan dengan peningkatan sudut trapezoid. Rongga trapezoid dipertingkatkan taburan ruang atau sisi buih ke kiri dan kanan tiang. Lajur trapezoid juga meningkatkan perubahan bentuk gelembung dari elips kepada bulatan dan sebaliknya dengan peningkatan masa atau ketinggian menegak. Akhir sekali, VOF-CSF telah digunakan untuk mengkaji kesan kelikatan cecair tanpa dimensi dan kesan bukan dimensi pekali tegangan permukaan pada bersama-paksi dan tautan gelembung selari serta trajektori kenaikan cecair bertakung. Ia telah mendapati bahawa masa yang tautan

dua buih bersama paksi menurun dengan kelikatan cecair yang mengurangkan pekali tegangan permukaan dan mengurangkan. Untuk buih tautan yang selari, tanpa dimensi jurang rata kritikal gelembung tautan (Sc) menurun dengan peningkatan diameter gelembung di bawah pengurangan pekali tegangan permukaan. Tetapi Sc meningkat dengan pengurangan kelikatan cecair. Apabila jurang rata awal gelembung yang lebih besar dari Sc; gelembung selari terpesona dengan kesan yang menjijikkan. Hasil daripada kerja-kerja ini mungkin boleh menyediakan pengetahuan asas dan juga berguna untuk mereka bentuk satu penyembur untuk gelembung ruangan reaktor yang sangat sukar untuk didapati daripada kajian eksperimen.

ACKNOWLEDGEMENTS

At first Alhamdulillah and thank you to the Almighty Allah who has created the whole universe.

Foremost, I would like to thank my supervisor Dr. Poo Balan Ganesan for the continuous support into me, for his patience, motivation, enthusiasm, and immense knowledge. His guidance has helped me in all the time of this work. I am glad that I have been his student.

I am especially grateful to Dr. Jaya Narayan Sahu and Dr. Ghufran Bin Redzwan for providing their funding support. I am likewise thankful to my friend Mr. Masum, Mr. Nasir and Mr. Iman who have encouraged me with continuously.

Thanks also goes to my parents, Md. Abdus Samad Talukder and Sherifon Nesa for their love, encouragement and patience. I also owe a lot to my sisters and brothers, Mr. Md. Amin and Mr. Md. Ali who have given me so much support, love and courage during this work.

Finally, I would like to acknowledge gratefully the University of Malaya for providing me the financial support from its HIR-MOHE project no. UM/HIR/MOHE/ENG/13 to accomplish this work. Thanks also go to the staff of this institute as well as university who helped directly or indirectly to carry out this work.

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SYMBOLS

$\vec{V}$	velocity vector, m/s
$\vec{F}$	volume force, N/m^3
g	gravitational acceleration, m/s^2
P	pressure, N/m^2
k	curvature of the interface
$\hat{n}$	unit vector
$\varepsilon_{g,\ het}$	gas hold up for heterogeneous bubbly flow.
$\varepsilon_{g,\ hom}$	gas hold up for homogeneous bubbly flow
d_b	bubble diameter, mm
Dt	column width, mm
d_o	orifice diameter, mm
r_o	orifice radius, mm
r_c	bubble curvature radius, mm
θ	instantaneous contact angle in degree
t_d	detachment time, s
d_p	departure diameter, mm
U_t or U_b	bubble terminal velocity, m/s
Ug	gas inlet velocity, m/s
d_e	bubble equivalent diameter, mm
E	bubble aspect ratio (d_h/d_w)
d_h	bubble height, mm
d_w	bubble width, mm
Re_t	terminal Reynolds number ($\rho_l U_b d_b/\mu_l$)

Re	orifice Reynolds number ($\rho_l U_g r_o/\mu_l$)
Bo or Eo	Bond number or Eotvos number (ρ_l g r_o^2/σ)
Mo	Morton number ($g\mu_l^4 / \rho_l\sigma^3$)
hc	critical flat gap, mm
Sc	non-dimensional critical flat gap, [-]
ρ_l	liquid density, kg/m^3
μ_l	liquid viscosity, Pa s
μ_r	reduced liquid viscosity, Pa s
σ_r	reduced surface tension coefficient, N/m
σ	surface tension coefficient, N/m.
μ*	non-dimension liquid viscosity [-]
σ*	non-dimensional surface tension coefficient, [-]

ABBREVIATIONS

CFD	Computational Fluid Dynamics
E–E	Eulerian–Eulerian
E–L	Eulerian–Lagrangian
VOF	Volume of Fluid
CSF	Continuum Surface Force
LS	Level Set
PLIC	Piecewise Linear Interface Calculation
BC	Boundary Condition