THE EFFECT OF CHANGING SURFACE TENSION WITH TEMPERATURE ON THE COALESCENCE OF TWO BUBBLES IN ZEROGRAVITY CONDITION

Yousuf Alhendal[1*], Fatima Alhendal[*2], Mohammad Alhendal[3]

[1]American University of the Middle East (AUM), State of Kuwait.
[*2]College of Technological Studies (CTS), Public Authority for Applied Education and Training, Kuwait.
[3]Australian College of Kuwait (ACK), State of Kuwait.

ABSTRACT

Calculations were performed to examine the effect of the temperature gradient (0.167 ≤ ΔT ≤ 0.33 K/mm) on the trajectories of a single bubble and two bubbles agglomeration in zero gravity. As the liquid temperature gradient increases, the bubbles clump are found closer to the axis of the cylinder. This is a technique for bringing multiple bubbles within a cylinder to its centre to coalesce into a large bubble. This allows for sensitivity and practical studies of various parameters and conducting the design.

Keywords: Marangoni flow; Thermocapillary; Two-phase flows; Bubbles coalescence; Surface tension gradient

1. INTRODUCTION

As temperature is set to gradient on the interface, the surface tension varies too, leading to shear stresses acting on the external fluid by viscous forces. This leads to the movement of mass fluids causing the movement of the fluid particle in the direction of the thermal gradient. This is called thermocapillary (Marangoni) flow. In normal gravity, this tends to be weighed down by the flow driven by buoyancy. The literature for zero-gravity experiment data limited to low Re and Ma, due to the difficulties in obtaining experimental results in microgravity (Kang et., 2008). We can work on computer simulations to understand the fundamental fluid physics, and assist in the design of microgravity experiments. The numerical method modellings turned out to be the ideal tool allowing the investigation of multiphase flow behaviour and capture of flow physics with more time and fewer cost. In 1959, Young et al. (1959) investigated for the first time the thermocapillary flow of bubbles and droplets with their linear model:

$$\sigma = \sigma_0 + \sigma_T (T_0 - T) \quad (1)$$

Where σ_o denotes the surface tension at a reference temperature T_o, and σ_T is the rate of change of surface tension with temperature The two most important parameters governing thermocapillary motion are the Reynolds and Marangoni numbers:

$$Re = \frac{RV_o}{v} \quad (2)$$

$$Ma = \frac{U_o.R}{\alpha} = Re.Pr \quad (3)$$

$$Pr = \frac{v}{\alpha} \quad (4)$$

$$V_T = \frac{\sigma_T \Delta T R}{\mu} \quad (5)$$

Here, R is the bubble radius, ν is the dynamic viscosity and α is the thermal diffusion of the surrounding fluid, and Pr is the Prandtl number.

2. VOF MODEL AND VALIDATION

Nitrogen bubble was placed 10 mm from the bottom (cold) wall using the region adaptation setting on Ansys-Fluent (v.13, 2011). The size of the computational wall-bounded domain was chosen as 120 x 60 mm with impermeable sides (see Fig. 1). For simulations, the properties of nitrogen and ethanol

*Corresponding Author: ya.alhendal@paaet.edu.kw

were taken as those given in Table (1) from Thompson et al. (1980). The VOF model with the UDF were examined and validated properly. The results in Fig. 2 shows that the surface tension coefficient was well coded, suggesting that it is an appropriate choice to solve thermocapillary problems (Alhendal et al. (2013,2016)).

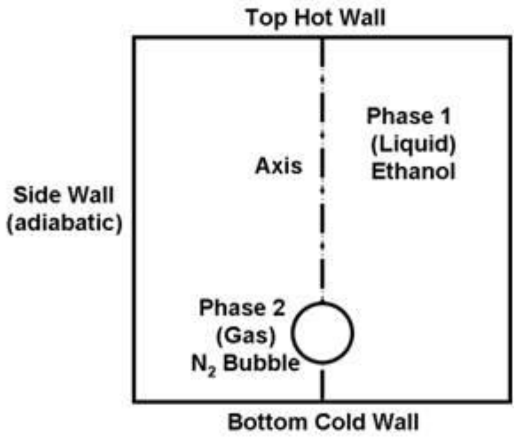


Fig.1. Schematic of bubble migration in a uniform temperature gradient

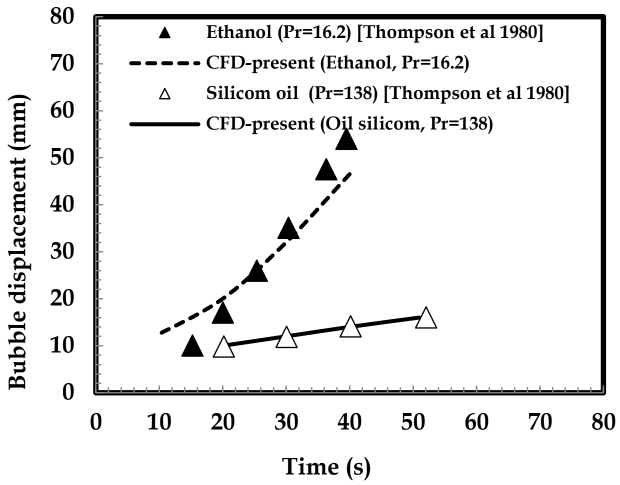


Fig.2. Sensitivity tests results (Pr=16.3) at time (t)=5 s

3. EFFECT OF LIQUID TEMPERATURE UPON BUBBLE MIGRATION

Fig.3 shows the 2D results for three different temperature gradients at time step = 5 s. As shown, the bubble absorbs heat at the front and rejects it at the cold end, as pointed by Nas & Tryggvason, 1993.

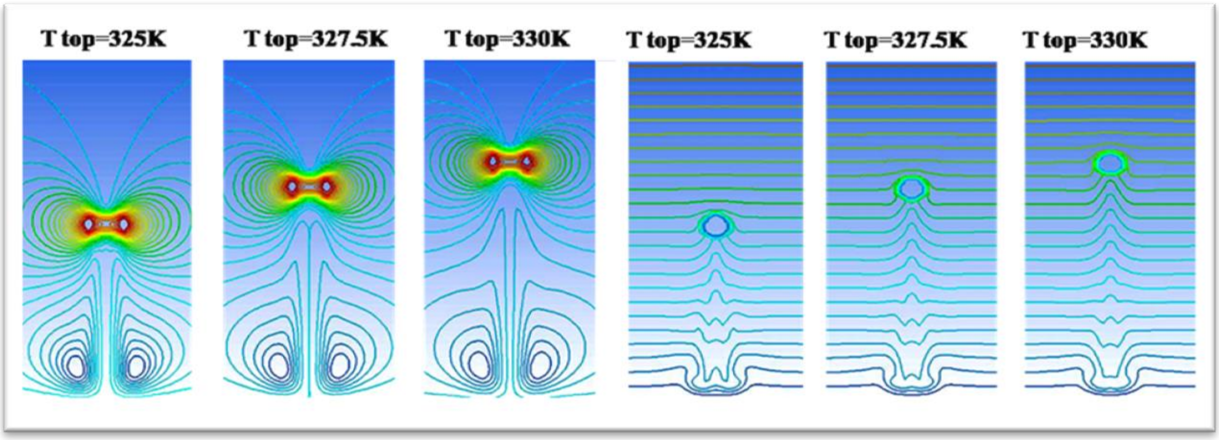
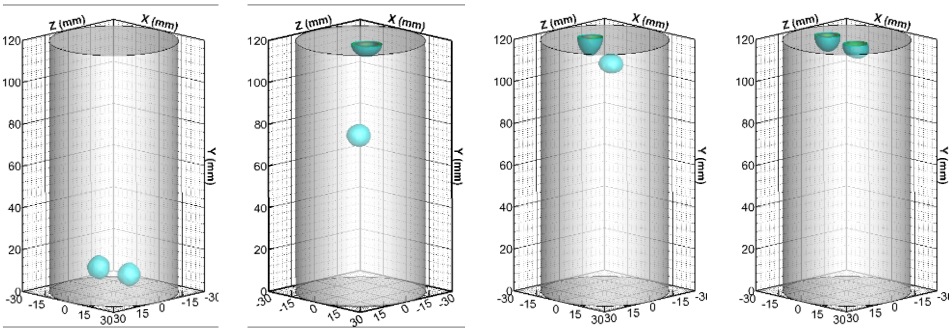


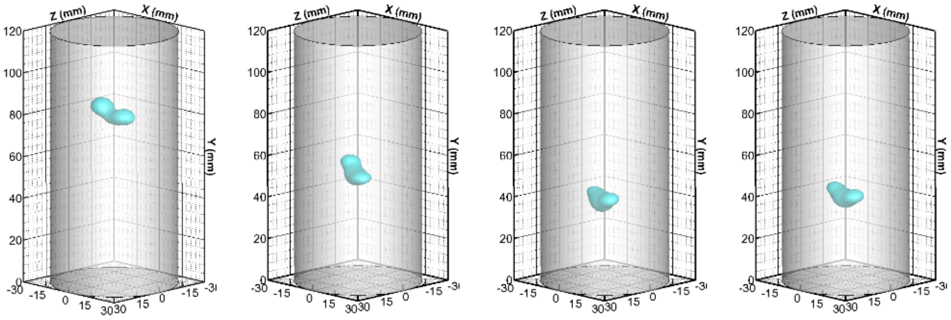
Fig.3 Temperature contours (bottom) and streamlines (top) for the single bubble (d=10 mm) at t=5 s, with bottom wall temperature 300K.

4. EFFECT OF LIQUID TEMPERATURE UPON BUBBLES COALESCENCE

In Fig. 4, we chose a temperature range between (320-337.5) K for the top wall while keeping the bottom wall at 300K, which gives Re and Ma a range from 205 to 410 and 3350 to 6700, respectively. The figure shows that the temperature differences between the upper and lower walls affect the bubble by moving faster for larger temperature differences, or slower for small temperature differences. For the ethanol fluid (Pr=16.3), a top side temperature higher than 337.5 K would not have much effect on the bubble velocity or coalescence, and lower than 320 K would move the bubble slower.



Initial position (all cases) | T_{top}=320 K, t=16 s | T_{top}=322.5 K, t=16 s | T_{top}=325 K, t=11.5 s



T_{top}=327.5 K, t=7 s | T_{top}=332.5 K, t=9 s | T_{top}=335 K _t=3 s | T_{top}=337.5 K_t=3 s

Fig.4 the coalescence sequence of 10 mm diameter bubbles for ($0.167 \leq \Delta T \leq 0.33$ k/mm).

5. CONCLUSIONS AND FUTURE WORK

The transient thermocapillary migration of single and double bubbles in a zero-gravity environment were numerically calculated by solving the Navier–Stokes equations with the energy equation. Ansys-Fluent (VOF) has been shown to be a powerful numerical method for a twophase flow simulation, and its ability to simulate surface tension as a function of temperature (Marangoni flow) using UDF. The present results show a critical presence of Marangoni bubble flow phenomena in a zero-gravity environment. Most experiments in microgravity have limitations such as time, but in computer simulations they can be dismissed, since any geometry can be simulated. Thus, numerical simulation has proven to be a valuable tool for studying complex problems under zero conditions. We explored the effect of temperature on the behavior of bubbles in zero gravity using ANSYS 13. The 3D simulations of a 2D axial symmetry states were complemented by providing techniques for bringing many small and immobile bubbles inside a cylinder to combine into a large bubble. These results can help determine the velocity of new migration and the behavior of gas bubbles by adjusting the temperature gradient. The results of this paper provide a new area of study and are intended to help support the field of research based on space applications.

ACKNOWLEDGEMENTS

This work supported and funded by Public Authority of Education and Training Research project No (TS-21-04), Research Title (Behavior of Bubbles and Droplets in a Zero-Gravity Environment Under the Influence of Temperature Gradients and Vibrations in the Rotating container).

References

[1] Kang, Q., Cui H. L., Hu L., & Duan L., (2008). On-board Experimental Study of Bubble Thermocapillary Migration in a Recoverable Satellite, *Microgravity Sci. Technology* (2008) 20:67–71-DOI 10.1007/s12217-008-9007-6.

[2] Young O., Goldstein, J. S. & Block, M. J. (1959). The motion of bubbles in a vertical temperature gradient. J. Fluid Mech. 6, 350-356.

[3] ANSYS-Fluent (2011). Users Guide.

[4] Thompson, R.L., DeWITT, K.J. & Labus, T.L., (1980). Marangoni Bubble Motion Phenomenon in Zero Gravity, *Chemical Engineering Communications* 5 299-314.

[5] Nas, S. & Tryggvason, G. Thermocapillary interaction of two bubbles or drops. *Int. J. Multiphase Flow* 29, 1117-1135.

[6] Yousuf Alhendal, Ali Turan, Peter Hollingsworth, Thermocapillary simulation of single bubble dynamics in zero gravity, Acta Astronautica, Volume 88, 2013, Pages 108-115, ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2013.03.017.

[7] Alhendal, Y., Turan, A. Thermocapillary Flow and Coalescences of Heterogeneous Bubble Size Diameter in a Rotating Cylinder: 3D Study. Microgravity Sci. Technol. 28, 639–650 (2016) https://doi:10.1007/s12217-016-9521-x