Critical bubble diameter for the reversal of lift force acting on single air-water bubble

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1. Introduction

Lift force acting on a bubble is one of traditional topic in 'two fluid model'. Lucas and Tomiyama(2011) emphasized the effect of lift force on void distribution in bubbly flow. They used the concept 'critical bubble diameter' as the condition that reversal of lift force occurs, and Tomiyama et al.(2002)'s correlation was used to calculate it. In the case of air-water bubble, the critical bubble diameter was obtained to 5.8mm from the correlation.

However, as noted by Li et al.(2016) there are discrepancies among the experimental results. Based on their experiment, Li et al.(2016) showed that critical bubble diameter was lower than 2.8 mm. Viscosity, shear ratio, bubble injection method, and surface contamination were considered as possible reasons on the discrepancy.

Therefore, on the universal understanding of lift force acting on bubble, now it is very unclear state. To solve the problem, experimental basis are crucial due to computational limitations of current CFD method. In this paper, experimental results on bubble shift in shear flow similar to Li et al.(2016) are presented. Although similar test condition is tried, this kind of experiment is valuable to do, due to rareness of the experimental data.

2. Experimental method

Whole experimental setup is similar to that of Yang et al.(2013), however, test section is enlarged (from 10cm x 10cm to 20cm x 20cm) and shear ratio dU_y/dx (from 3 rad /s to 0.5 rad/s) is lowered. Linear shear flow is generated at the inner corner of experimental loop as shown in Fig. 1, and flowed into test section from topside. Turbulence intensity is maintained to lower than 15% in the test region. With mean inlet velocity 0.1m/s, following velocity profile is made at -1m < y < -0.5m and 5cm < x, z < 15cm.

$$U_y = w(x-0.5D)+U_{center} \qquad (1)$$

where w is shear ratio at the test section(-0.5rad/s), D is the width of the test section(0.2m), and U_{center} is the velocity at x = 0.5D(~0.11m/s). Velocity components of other directions are well removed. Filtered water and air at room temperature and atmospheric pressure are used.

Transparent glass tube is used for bubble injection nozzle. It is horizontally inserted to lower side of test section and curved 90 deg to upward for vertical upward injection of bubble. Similar to Li et al.(2016), 1mm inner diameter nozzle is used. Bubble is released by water pulling, however, it seems that it is like pinch off method. Because inner diameter of nozzle is much smaller than equivalent diameter d of bubble. For the bubble injection method, please refer to Wu et al.(2002).

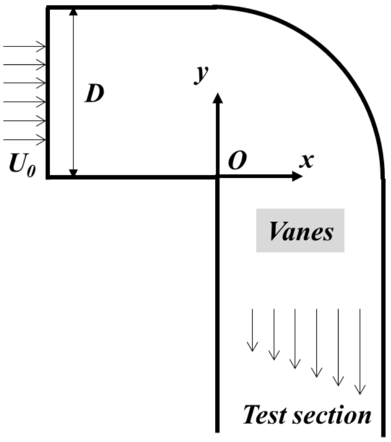


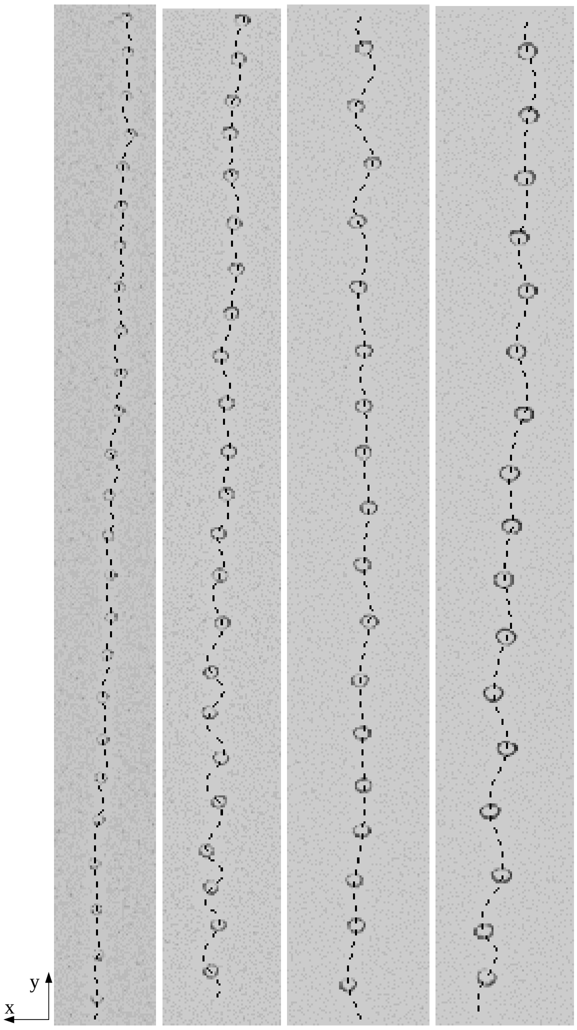
Fig. 1. Structure of the linear shear flow generator

Similar to Li et al.(2016), d=2.08, 2.62, 2.82, 3.26mm air-water bubbles are tested in this experiment. The test bubble is inserted at y = -0.9m, x and z = 0.5D. High speed camera is used to capture the bubble shape and trajectory at -0.7m < y < -0.5m with 100 frames/sec. In this experiment, movement of bubble on xy plane at z=0.5D is only captured.

3. Results

In Fig. 2, trajectories of each bubble are presented with same camera capture scale. All bubbles shows periodic movement and shift to –x side where liquid velocity is small. It indicates that lift coefficient is negative, i.e. all the tested bubbles have diameter larger than the critical bubble diameter. Shape of bubbles are also demonstrated (period=50ms) together with its trajectory. As shown in the Fig. 2, shapes of bubble are ellipsoidal.

Except for d=2.82mm case, consistent shift is observed and can be linearly fitted as shown in Fig. 3. In the case of d=2.82mm case, it seems that bubble rising pattern is not saturated, because it changes its sign of movement in the test section. From these linear fitting curves, lift coefficient of -1~ -2 can be obtained which is similar range that of Li et al.(2016).



(a)d=2.08mm (b)d=2.62mm (c)d=2.82mm (d)d=3.26mm

Fig. 2. Trajectories and shapes of tested each bubble

4. Conclusion

Shift of air-water bubble in linear shear flow is experimentally investigated. It is observed that similar trend to results of Li et al.(2016) can be well reconstructed from the current experimental setup. Based on the experimental results, it seems that critical bubble diameter for air-water bubble is lower than 2mm like as transitional diameter for wake instability of free rising air-water bubble. More studies are needed to clarify the exact and universal trend of critical bubble diameter.

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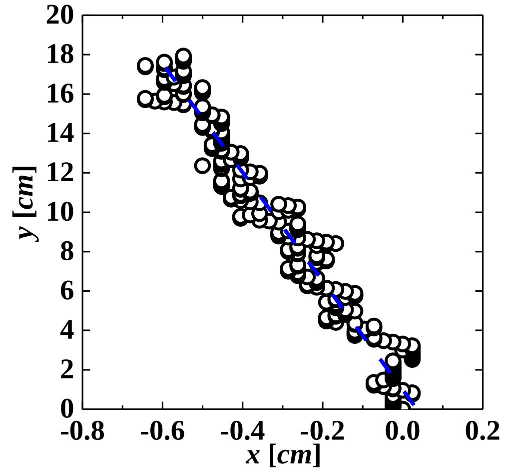
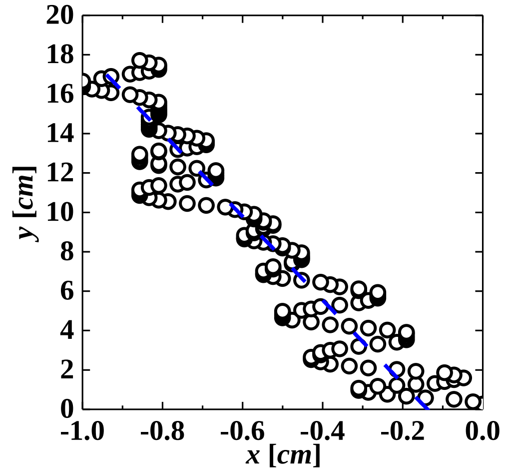


(a)d=2.08mm



(b)d=3.26mm

Fig. 3. Trajectories and linear curve fitting for two cases

REFERENCES

[1] D. Lucas, A. Tomiyama, On the role of the lateral lift force in poly-dispersed bubbly flows, International Journal of Multiphase Flow, Vol.37, p. 1178-1190, 2011.

[2] A. Tomiyama, H. Tamai, I. Zun, S. Hosokawa, Transverse migration of single bubbles in simple shear flows, Chemical Engineering Science, Vol.57, p. 1849-1858, 2002.

[3] Z. Li, Y. Zhao, X. Song, H. Yu, S. Kiang, M. Ishii, Experimental investigation of single small bubble motion in linear shear flow in water, Nuclear Engineering and Design, Vol.305, p. 334-346, 2016.

[4] S. Yang, Y.S. Choi, J. Y. Lee, Measurement of lift force of air bubble in linear shear flow of water using L-channel(ICMF2013-435), 8th International Conference on Multiphase Flow, Jeju, Korea, , 2013.

[5] M. Wu and M. Gharib, Experimental studies on the shape and path of small air bubbles rising in clean water, Physics of Fluids, Vol.14, 7, p.49-52, 2002