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A Numerical Study on Rising Characteristics of Condensing Bubble using VOF Model

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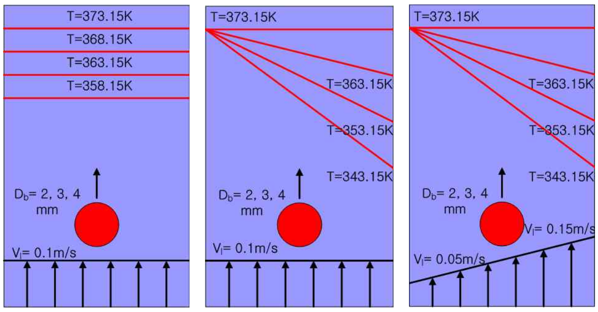
1. Introduction

In nuclear engineering field, the understanding of the behavior of condensing bubble is very important to analyze and model the subcooled boiling flow. Though there have been many numerical studies on bubble behavior, most researches focused on the analysis of the behavior of adiabatic bubble so that the understanding of the behavior of condensing bubbles is insufficient as yet. In this study, the behavior of condensing bubble was investigated by using FLUENT code coupled with the UDF modeling of bubble condensation proposed by Ref. 1. The analysis of bubble behavior is performed qualitatively by comparing with the behavior of an adiabatic bubble under various conditions.

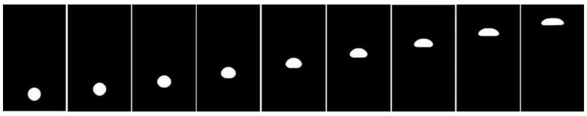
2. CFD Simulation Results

In order to understand the effects of condensation on bubble behavior, the two-dimensional bubbles shown in Fig. 1(a) were simulated in Cartesian coordinates. The analysis of the behavior of condensing bubble was performed at different degrees of liquid subcooling with initial bubble diameters of 2, 3, and 4 mm, respectively. Here, the adiabatic bubble simulations (T = 373.15K) are used as criteria for comparison with the behavior of condensing bubbles.

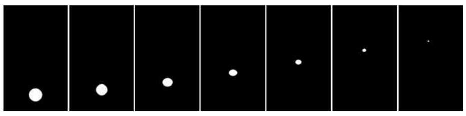


(a) Base case (b) Temperature gradient (c) Velocity gradient
Fig. 1 Schematic Diagrams of Condensation Simulations

Figure 2 qualitatively contrasts the time-dependent behavior of the condensing bubble with that of the adiabatic bubble. For the adiabatic-bubble simulations (see Fig. 2(a)), each bubble rises up in the liquid whilst retaining its initial bubble size; only the bubble shape is changed by the hydrodynamic force. The bubble shape varies continuously from spherical to ellipsoid, and then hemispherical. In the subcooled system, on the other hand, the shape of the adiabatic bubble changes from spherical to ellipsoid and returns to the spherical shape again (see Figs. 2(b)). For the condensing bubbles, the deformation phenomenon nearly tends to disappear and the bubble remains nearly spherical throughout the entire lifetime. The bubble size decreases due to bubble condensation so that the deformation aspect of the condensing bubble differs from that of an adiabatic bubble.



(a) Bubble Shape Sequence (D_b =3mm, ΔT=0K)



(b) Bubble Shape Sequence (D_b =3mm, ΔT=10K)

Fig. 2 Comparison of Adiabatic and Condensing Bubble

2.1 Effect of Condensation on Bubble Velocity

In general, the rising bubble in the liquid accelerates to reach the constant terminal velocity determined by the initial bubble size and properties of each phase. However, these characteristics might be applied only to the adiabatic bubble. Figure 3 shows the time-dependent rise velocity of a 3mm bubble at different degrees of liquid subcooling, representatively. The adiabatic bubble reaches the constant terminal velocity but the rise velocity of the condensing bubble increases continuously, as the bubble loses its own mass every moment. As the liquid subcooling increases, due to the increase in bubble condensation, the bubble velocity increases rapidly and the final velocity of the condensing bubble becomes higher than the terminal velocity of the corresponding adiabatic bubble.

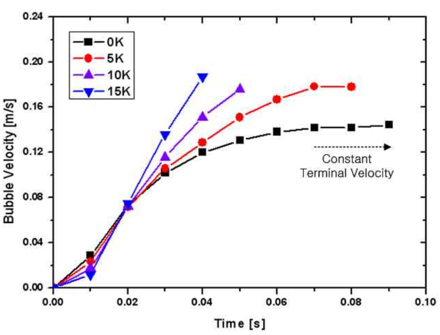


Fig. 3 Time-dependent Bubble Velocity (D_b =3 mm)

2.2 Effect of Condensation on Bubble Rise Distance

Figure 4 shows the time-dependent positions of 4mm bubbles at different levels of liquid subcooling. Each bubble is illustrated with a time interval of 0.01s. The bubble rise distance is reduced because of the shorter lifetime as the liquid subcooling increases. However, the last position of each condensing bubble should be noted. During the limited bubble lifetime, the condensing bubble moves longer distances than the adiabatic bubble. After the medium stage of the bubble lifetime, the condensing bubble accelerates so that the bubble moves faster and then disappears. This phenomenon is particularly noticeable in a large bubble with a longer lifetime wherein the bubble accelerates sufficiently.

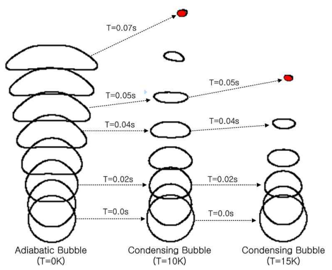
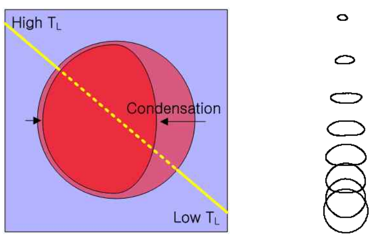


Fig. 4 Bubble Rise History (D_b =4 mm)

2.3 Effect of Condensation on Moving Trajectory

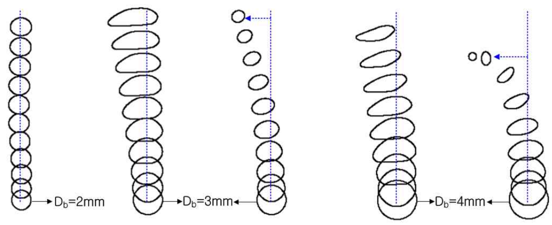
In order to understand the effects of the difference in the local condensation amount due to the local liquid temperature difference on the bubble moving trajectory, shown in Fig. 1(b) were simulated. As shown in Fig. 5(a), it is easily guessed that since the condensing rate in the right side of the bubble is larger than that in the left side of bubble, the bubble shape is changed into an asymmetrical shape; then moving trajectory is also changed. However, the effect of difference in the local condensation seems to be negligible. Figure 5(b) shows that there is no asymmetrical change in shape and the condensing bubbles rise nearly upright.



(a) Speculative Bubble Deformation (b) D_b =4mm,ΔT=10K
Fig. 5 Moving Trajectory and Bubble Deformation

In order to investigate the effect of condensation on the bubble moving trajectory, bubbles shown in Fig. 1(c) were simulated in linear shear flow. The calculated moving trajectories under a liquid velocity gradient are shown in Fig. 6 together with the bubble shapes.

For the 2mm bubble in Fig. 6(a), the adiabatic bubble moves along more or less sinuous paths but there is no noticeable change in the rise trajectory compared with those of the 3mm and 4mm bubbles. On the other hand, for larger bubbles (D_b = 3 and 4 mm), prominent changes are observed in the moving trajectory and bubble shape. As shown in Fig. 6(b), the calculated bubble shapes change from spherical to wing-shaped. For the condensing bubble, the shape changes from spherical to wing and finally to ellipsoidal (see Figs. 6(c) and 6(d)). In addition, as the subcooling increases, the bubble migrates more toward a lower velocity region (see Fig. 6(e)). It can be seen that condensation accelerates the lateral migration of the bubble in liquid with a velocity gradient.



(a) ΔT=0K (b) ΔT=0K (c) ΔT=5K (d) ΔT=5K (e) ΔT=10K
Fig. 6 Bubble Rise History

Figure 7 shows a representative, time-dependent bubble diameter in liquid with a temperature gradient. Since the 4mm bubble rises upright in liquid without a velocity gradient (see Fig. 5(b)), the bubble size decreases nearly linearly. However, the 4mm bubble in the linear shear flow migrates toward the higher-temperature region in the liquid (see Figs. 1(c) and 6(e)) so that the bubble lifetime becomes longer due to the decreased amount of condensation.

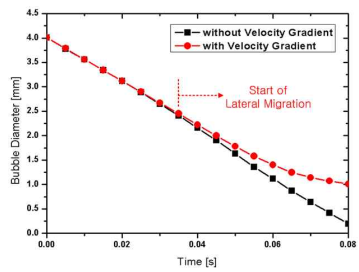


Fig. 7 Comparison of Bubble Diameter (D_b =4mm, ΔT=10K)

3. Conclusions

The results of this study show the effect of condensation on bubble behavior well. Consequently, it is confirmed that the behavior of the condensing bubble is significantly different from that of the adiabatic bubble. It is expected that UDF modeling of bubble condensation will be a useful computational fluid dynamics tool for a wide range of two-phase simulations.

REFERENCES

[1] S. S. Jeon, S. J. Kim, G. C. Park, CFD Modeling of Single Vapor Bubble Condensation Using VOF Model, NURETH-13, 2009.