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Study on Bubble Dynamic Characteristics of Lead-Bismuth Alloy Under Natural Circulation

Zhanzhong LIU and Guojun LI[1]
MOE Key Laboratory of Thermo-Fluid Science and Engineering, Xi'an Jiaotong University, Xi'an 710049, China

Abstract. In order to guide the practical application of lead-bismuth alloy (LBE) bubble lift pump, the dynamic characteristics of nitrogen bubbles with different diameters in liquid Lead-bismuth alloy (LBE) were studied based on the Volume of Fluid (VOF) model, and the changes of bubbles' morphology and velocity during the movement were analyzed. The results show that the smaller the radius of the bubble is, the more drastic the change of its initial velocity and the smaller its maximum velocity are. For the small bubble, there is no bubble shedding in the process of its movement, only when the radius of the bubble reaches a certain value, the phenomenon of small bubble shedding will occur.

Keywords. Bubble, lead-bismuth alloy (LBE), natural circulation

1. Introduction

In order to cope with energy shortage and environmental pollution, human beings need new clean energy. Nuclear energy is currently recognized as a realistic and feasible clean energy that can replace fossil fuels on a large scale. However, people have to face the difficult problems of nuclear waste disposal while utilizing nuclear fission energy. It is necessary to study the transmutation method of long-lived nuclear waste with high radioactive toxicity. This can be achieved through the interaction between nuclear waste and neutron reactions and radiation capture. Accelerator driven subcritical system (ADS) is the most promising tool to realize this transmutation [1].The lead and bismuth alloy cooling ADS device with advanced design concept adopts bubble lifting pump instead of mechanical pump for circulation, that is, injecting inert gas into lead and bismuth alloy to improve the natural circulation capacity of lead and bismuth alloy [2].Therefore, it is necessary to study the two-phase flow characteristics of lead-bismuth alloy and inert gas for the safety of the system. Chen et al. used moving particle semi-implicit (MPS)method and self-programmed FORTRAN language to conduct two-dimensional numerical simulation of the transient dynamic behavior of a single argon gas bubble in the whole process from static to full development in liquid lead-bismuth alloy, and obtained the relationship between bubble deformation characteristics and rising speed [3]. Based on the drift flow model, Zuo et al. analyzed the influence of gas mass flow rate, mass gas

[1] Corresponding author, Guojun Li, MOE Key Laboratory of Thermo-Fluid Science and Engineering, Xi'an Jiaotong University, Xi'an 710049, China; E-mail address: liguojun@xjtu.edu.cn.

holdup, bubble diameter and height of riser on the natural circulation enhancement ability of bubble lift pump by using the cavitation share prediction model and friction pressure drop prediction model [4].Wang et al. simulated the development behavior of a single nitrogen bubble in liquid LBE from static to fully dynamic based on diffusion interface method, and obtained the relationship between bubble rising speed and deformation with time [5].

This article uses the VOF model to simulate the single nitrogen rise behavior of bubbles in the liquid lead bismuth alloy, studies the different radius of nitrogen gas bubbles in lead bismuth alloy in the movement of the dynamic characteristics, analyzes the bubble rising velocity in the process of change, gives a LBE nitrogen bubble lift pump recommend bubble radius, used to guide the application of bubble lift pump.

2. Calculation Model

2.1. Geometric Models and Grids

In this study, a two-dimensional model with a width of 0.08m and a height of 0.16m was used. In order to eliminate the influence of the wall surface on the bubble motion characteristics, the initial coordinates of the center of the nitrogen bubbles R=3mm, R=4mm, R=5mm and R=6mm are (0.04, 0.02), while the initial coordinate of the center of the nitrogen bubbles R=7mm is (0.04, 0.03). After grid independence verification, 340,000 grids were used for calculation. The geometric model and grid are shown in Figure 1. The simulated temperature is 473.15K. According to the literature [6].At this temperature, the density, dynamic viscosity and surface tension of the LBE are 10496.7kg/m^3, 2.43E-5 kg/ (m^3·s) and 0.406N/m respectively. The density of nitrogen is 0.7118kg/m^3, and it's dynamic viscosity is 2.51E-5 kg/ (m^3·s).

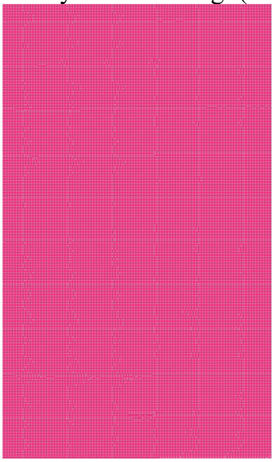


Figure 1. Compute domain grid.

2.2. Calculation Equation

For incompressible fluid, the continuity equation is:

$$\nabla \cdot \vec{u} = 0 \tag{1}$$

The momentum equation for considering surface tension is [7]:

$$\rho\left(\frac{\partial u}{\partial t} + (\vec{u} \cdot \nabla)\right) = -\nabla p + \mu \nabla^2 \vec{u} + F + \rho g \tag{2}$$

Where, $\vec{u}$ is the velocity vector, ρ is the density, p is the pressure, μ is the dynamic viscosity, F is the surface tension per unit volume, g is the gravitational acceleration.

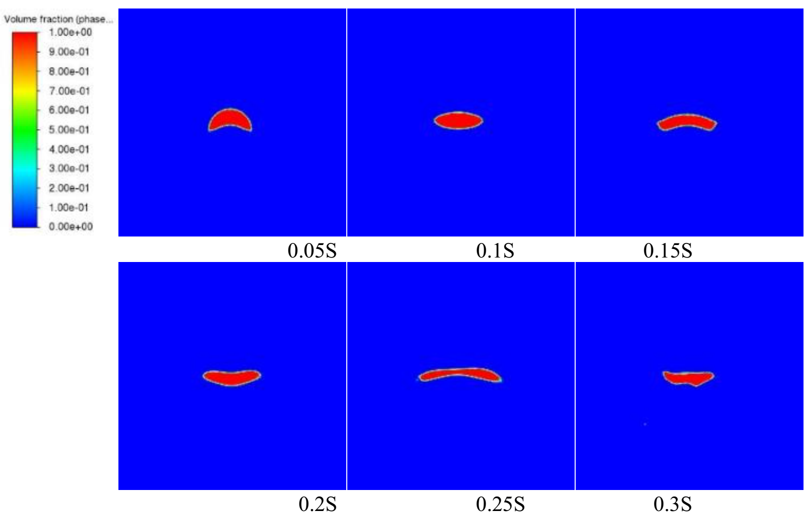
FLUENT software is used for simulation calculation. The bubble interface volume fraction C of the VOF model satisfies the following equation:

$$\frac{\partial C}{\partial t} + \nabla \cdot (uC) = 0 \tag{3}$$

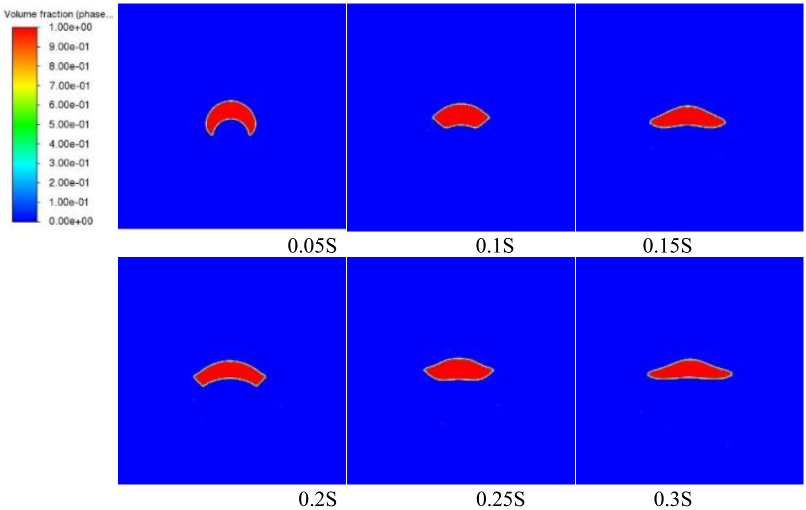
When C=1, it means that the region is completely filled with gas. When $0 < C < 1$, the region is the gas-liquid interface. When C=0, the region is completely filled with liquid.

3. Results and Discussions

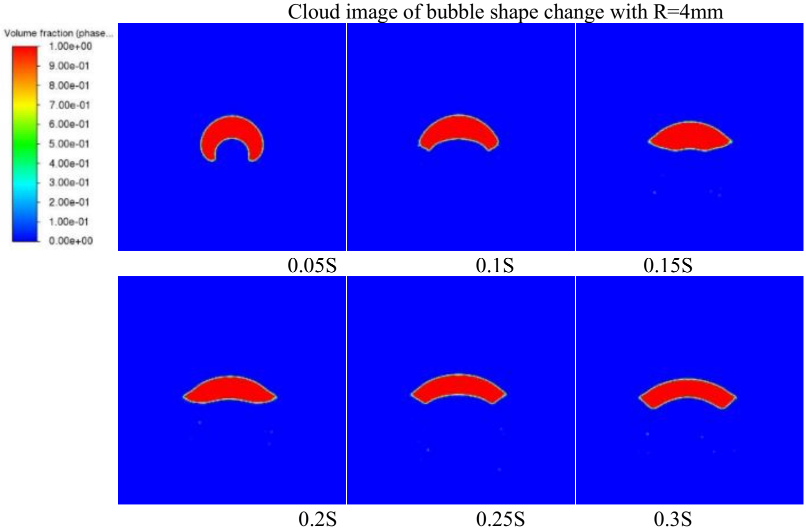
3.1. The Shape Changes of Bubbles During Movement



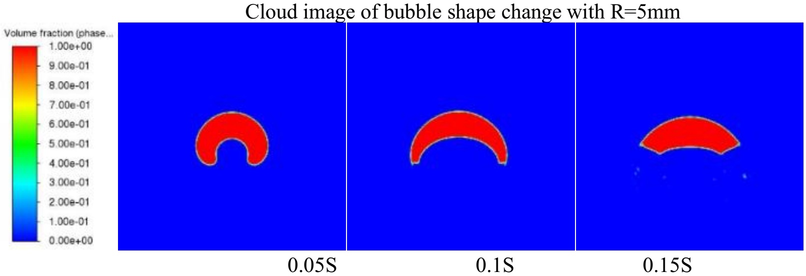
Cloud image of bubble shape change with R=3mm



Cloud image of bubble shape change with R=4mm



Cloud image of bubble shape change with R=5mm



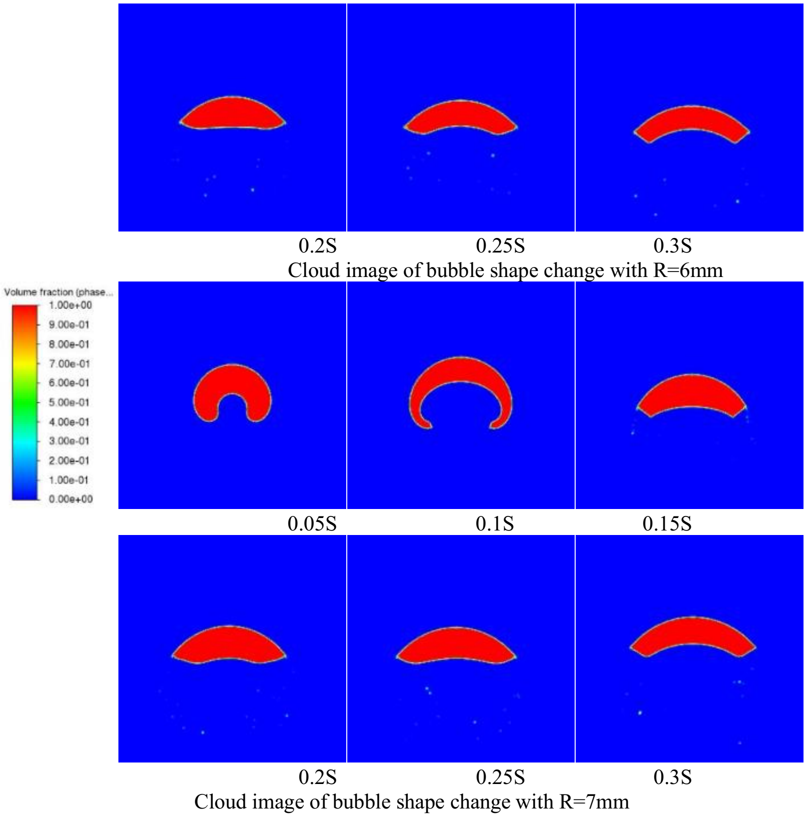


Figure 2. Shapes of bubbles with different diameters.

Fig.2 is the Shapes of bubbles with different diameters in the process of movement. It can be seen from the figure that, for bubbles with small radius (R=3mm and R=4mm), their shape rapidly changes to crescent shape first, then gradually to cake shape, and finally to coronal shape during their movement, and there is no phenomenon of small bubbles falling off during the whole process. For larger radius bubbles (R = 5 mm, R = 6 mm and R = 7 mm), in the process of the movement, air bubble at the bottom of the gradual invagination, form quickly into cashew shape first, then to the bridge arch, due to the small bubbles off at this moment, the bridge arch of bubble becomes thicker cap form, as the movement of bubbles continue, continue at the bottom of the retraction, the bubble thin again, eventually it stabilizes into a coronal shape. In addition, for bubbles that have smaller bubbles falling off, the shedding time of small bubbles is about 0.15s. And the larger the radius of the bubble, the more bubbles. For the lead - bismuth alloy bubble lift pump, the falling bubbles will not only affect the stable movement of the next bubble, but also affect the normal heat transfer of lead - bismuth alloy because the small bubbles will adhere to the wall surface, which may cause a security incident. Therefore, for the LBE nitrogen bubble lift pump, the radius of the bubble should not exceed 4mm.

3.2. The Change in the Velocity of the Bubble

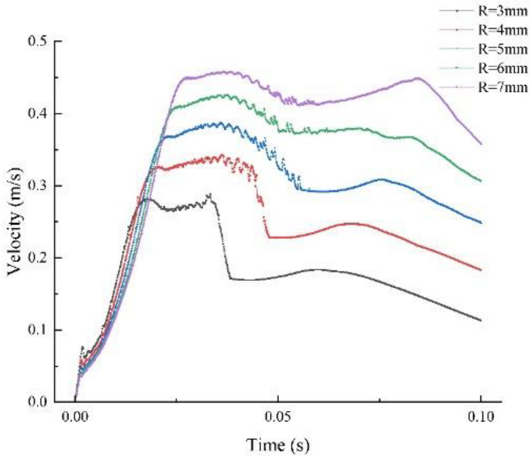


Figure 3. Velocity curves of bubbles with different diameters.

Fig.3 shows the velocity variation trend of bubbles with different diameters during their movement. It can be seen from the figure that the velocity variation trend of bubbles with different diameters is basically the same in the process of movement. They all reach the maximum velocity in a very short time, and then the maximum velocity fluctuates up and down for a period of time, and finally decreases gradually. For the bubble with smaller radius, its initial velocity changes more greatly. Obviously, the velocity of the bubble with R=3mm is the largest at 0.0005s, which is related to the surface tension of the bubble. With the further deformation of the bubbles, the small bubbles still maintain a high velocity, and reach the maximum velocity of 0.28m/ S at about 0.18s. After that, the small bubbles will fluctuate up and down at the maximum velocity for a long time. ; For the large bubble, its velocity is always lower than that of the small bubble before it reaches its maximum velocity, but due to different surface tension, the maximum velocity of the large bubble is obviously higher than that of the small bubble, and the maximum velocity increases with the increase of the bubble radius. In the practical application of the LBE nitrogen bubble lift pump, the speed of the LBE should not be too high or too low in order to ensure that the heat generated by the reactor can be taken away in time. Too fast for the LBE to fully absorb the heat generated by the reactor; If the speed is too small, local temperature is easily too high, which will seriously affect the safe operation of nuclear power. Therefore, combined with the analysis of the change of the shape and the change of the speed of the bubble in the process of the bubble movement, for the LBE nitrogen bubble lift pump, the radius of the bubble should be 4mm.

4. Conclusions

1. For LBE nitrogen bubble lift pump, when the radius of bubbles is small (R=3mm&R=4mm), no bubble falls off; When the radius of bubble is large (R=6mm&R=7mm), small bubbles will be generated in the process of bubble movement, and the larger the bubble radius is, the more bubbles will fall off.

2. For LBE nitrogen bubble lift pump, the velocity variation trend of bubbles with different initial radius is consistent. And, the maximum velocity of the bubble is proportional to the radius of the bubble.
3. For LBE nitrogen bubble lift pump, different radius of bubble leads to different maximum velocity. Combined with practical application, the recommended nitrogen bubble radius is 4mm.

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