MOTION OF BUBBLE RINGS IN VISCOUS FLUID

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Summary The bubble ring dynamics in a viscous fluid was studied by experiments and modelling. It is found that the increases of the density ratio and the core size lead to larger ring radius; higher initial circulation and Reynolds number cause faster bubble ring velocity and restrain its radial expansion rate. The increase of the Reynolds number or Bond number cause instability of the ring, and result in ring bubble breaking into the small bubbles. The number of small dispersed bubbles depends on the wave number of a perturbation.

I. INTRODUCTION

Vortex ring bubbles can be considered as one of important forms of multiphase flows and vortex motion. Ruban and Rasmussen (2003) made a theoretical study of the ideal incompressible irrotational flows with a toroidal bubble. Rogers et al. (2005) conducted a study of buoyant plumes and vortex ring driven by an autocatalytic reaction. More recently, Joseph et al. (2007) discussed the problem of the rise of a toroidal gas bubble in a viscous liquid. To our knowledge, all numerical studies are limited to either ideal fluid or irritation flow. Modeling of three-dimensional bubble ring in a viscous incompressible fluid has not been reported. In the present study, we simulate a three-dimensional motion of a bubble ring with circulation in a viscous incompressible fluid by using the lattice Boltzmann method (LBM). We systematically investigate the effects of various parameters (such as the circulation strength, the core size, the density ratio, the surface tension and viscosity) on the bubble motion.

II. EXPERIMENTS AND NUMERICAL MODELS

Experiment Set-up

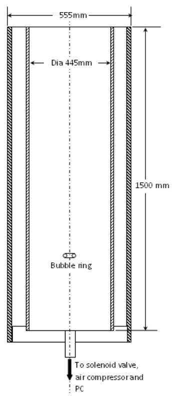

Figure 1. Experimental apparatus: Vertical Plexiglas Tank.

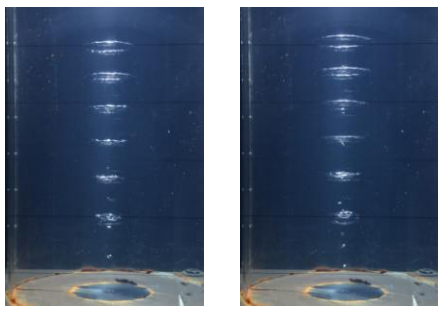

Figure 2. Multiple-exposed picture of a bubble ring rise upward, left). pressure 14 psi, duration 8 ms; right). pressure 14 psi, duration 12 ms.

Lattice Boltzmann method flow configuration

Consider the motion of a bubble ring with a circular cross-section and density ρ_2 in a viscous incompressible fluid of density ρ_1. The bubble ring with radius R_0 and circulation γ_0 is initially placed at the vertical position $z_0 = 3R_0$, as shown in Fig. 3.

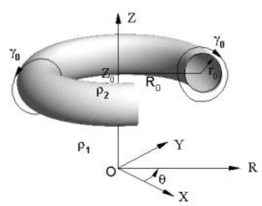

Fig. 3 Schematic of the coordinate system and a typical vortex ring bubble.

The initial vorticity distribution of the vortex ring bubble is assigned by a Gaussian function. The main dimensionless variables governing the flow and employed in this paper are defined as follows,

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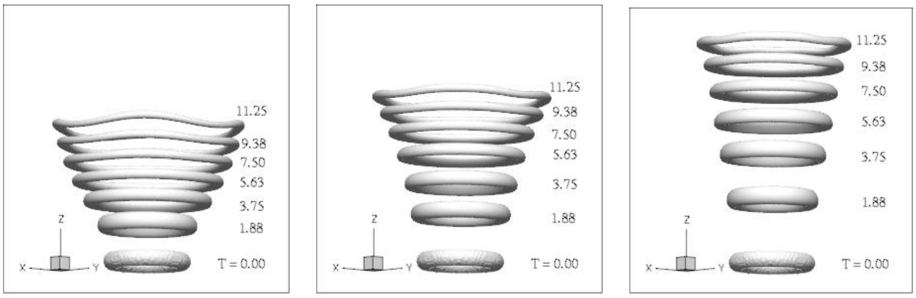
$$U=\frac{u}{\sqrt{gR_0}},\quad T=t\sqrt{\frac{g}{R_0}},\quad C_0=\frac{r_0}{R_0},\quad \Gamma=\frac{\gamma}{4\pi R_0\sqrt{gR_0}},\quad \lambda=\frac{\rho_1}{\rho_2},\quad R_e=\frac{2r_0\sqrt{gR_0}}{\nu},\quad B_o=\frac{(\rho_1-\rho_2)gr_0^2}{\sigma}$$

III. RESULTS AND DISCUSSIONS

Effect of initial circulation strength, Γ_0



(a) (b) (c)

Fig.4 Evolution of bubble ring with time for Re = 40, Bo = 10, λ = 100, C = 0.25 and different Γ0. (a) Γ0 = 1.5, (b) 2.5, (c) 3.5.

Effect of initial core size, C_0

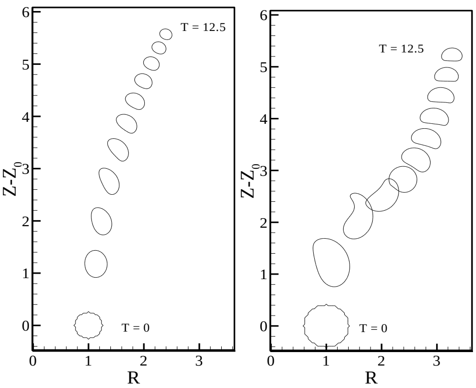


Fig.5 Evolution of bubble ring with time at Re = 40, Bo = 100, λ = 100, Γ_0 = 3, and different C_0 = 2.5 (left), = 4 (right).

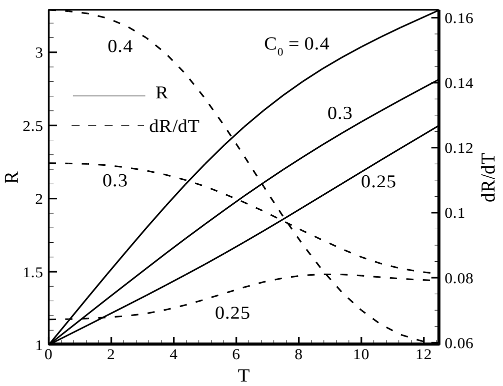
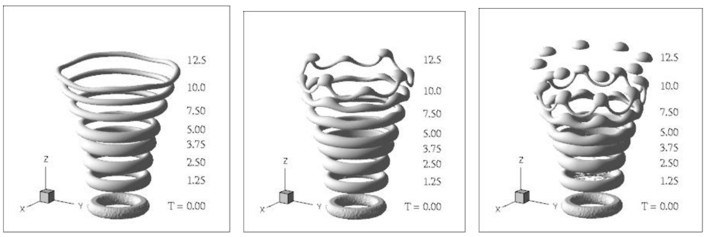


Fig.6 Variation of the radius R and its expansion rate with time.

Effect of surface tension, B_0



(a) (b) (c)

Fig.7 Influence of the surface tension on bubble ring for Re = 40, Γ_0 = 3.0, λ = 100, C = 0.25 and different B0. (a) B0 = 10, (b) 40 and (c) 50.

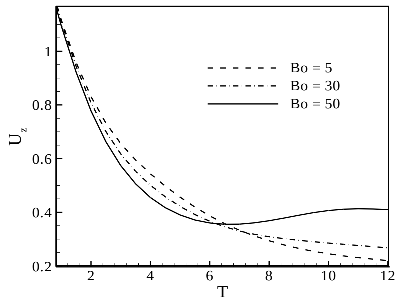


Fig. 8 Variations of the rise velocity Us with time for Re = 40, Γ_0 = 3.0, λ = 100, C = 0.25 and different B_0.

CONCLUSIONS

Our results revealed that the increases of the density ratio and the core size lead increase of the ring radius, the increases of the initial circulation and Reynolds number result in the increase of the rise velocity of the bubble and restrain its radial expansion rate. The increases of both the Reynolds and Bond numbers will enhance the instability of the ring, and even bring about the bubble ring breaking into the small bubbles.

References

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