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Bubble behavior in magnetic fluid and its applications

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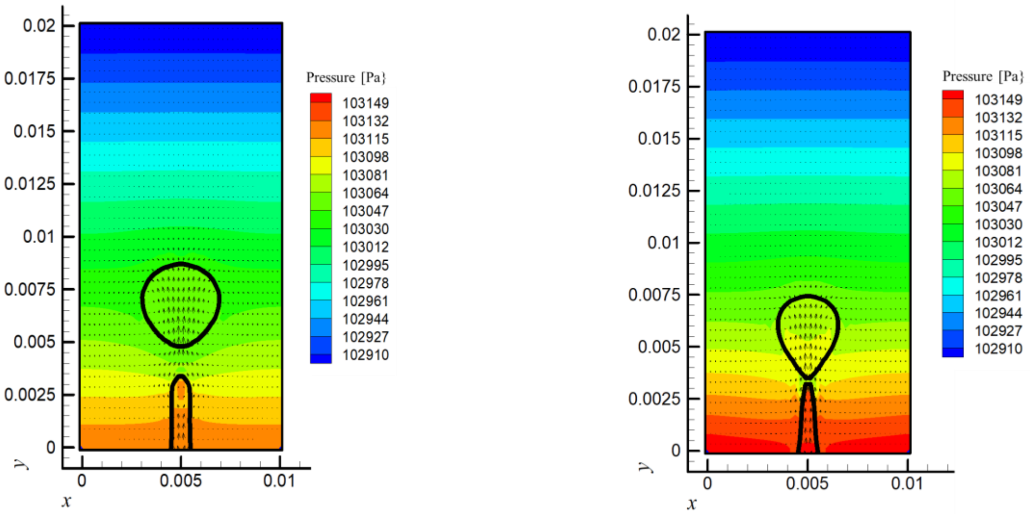
ABSTRACT Bubble behavior in a magnetic fluid is important in many industrial applications. For example, Nakatsuka et.al. have investigated vapor bubble deformation in boiling magnetic fluid and indicated that it can enhance the heat transfer capacities [1]. Authors have been proposed controlling techniques using magnetic fluid, that are gas flow rate and boiling heat transfer by magnetic field [2][3]. In order to give better understanding to characteristics of bubble behavior in magnetic fluid, it is desirable to visualize the bubble deformation in a magnetic fluid. However, visualization of bubble and flows in magnetic fluid is extremely difficult because visible light cannot be passed though magnetic fluid. In other approaches to characterize bubble behavior in magnetic fluid, a numerical analysis is promising. Ueno et al. and Korlie et al. [4][5] have calculated a bubble behavior in a magnetic fluid by using VOF (Volume of Fluid) method. They reported a bubble elongation along the uniform magnetic field. However, the dynamic characteristic and the distribution of magnetic flux density around bubble have not yet fully verified and discussed.

In the present study taking into consideration of the self-correcting procedure as a magnetic field solver, the deformation process of unit bubble detached from an orifice and flow fields around the bubble under non uniform magnetic field are numerically investigated. Furthermore, in order to confirm the accuracy of calculation, visualization test using diluted magnetic fluid is carried out.

As governing equations, continuity, incompressible Navier-Stokes equation with gravity term and magnetic body force term, and advection equation of capturing interface are used for simulation of magnetic-gas two-phase flow. Gas bubble deformation from an orifice with and without non-uniform magnetic field is calculated. The calculation domain is 0.01×0.02 m and mesh number is $(nx,ny)=(40,80)$. As physical properties of magnetic fluid and air, densities ρ_{mf}=1250.0 kg/m3, ρ_{gas}=1.1763 kg/m3, viscosities η_{mf}=0.04 Pa·s, η_{gas}=1.86×10-5 Pa·s and surface tension coefficient σ=0.032 N/m^2 are used. The simulation was obtained with slip boundary conditions for the left and right walls with flow out boundary condition for top wall. The operated conditions were as follows: inlet velocity of gas v_{in}=0.1 m/s from a submerged orifice where is set at center bottom wall, orifice diameter D_{orifice}=0.5 mm.
Fig. 1(a) and (b) show flow fields and the shape of rising bubbles with pressure distributions (a)

without magnetic field and (b) with magnetic field of 80 mT. In case (b) (under non-uniform magnetic field), bubble grows earlier than that without magnetic field. From the results of the pressure distribution in Fig. 1, it is found that the pressure near bottom wall in the case of (b) become higher than that in the case of (a) due to the magnetic pressure. From the results of the velocity vectors in Fig. 1, it is also found that the velocity near bottom wall in the case of (b) is larger than that in the case of (a). The results imply that the magnetic pressure accelerates the detached velocity of the bubble under applied magnetic fluid. Therefore, by applying non-uniform magnetic field to the growth bubble, the magnetic pressure promotes detachment of growth bubble from an orifice.

Keywords: *Magnetic fluid, Bubble, Finite volume method, Volume of fluid, Visualization.*



(a) Without magnetic field (b) Under non-uniform magnetic field

Fig. 1 Velocity vectors, contour lines of level-set function and pressure distribution

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