A new model of buoyancy-driven bubble coalescence with deformation effect

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In low viscosity magma like basalts, a buoyant force can no longer be ignored. Bubbles move upward by buoyant force and approach each other. They coalesce when approached sufficiently and become larger. The large bubbles move upward quickly and release their gas contents to the surface. It relates to episodic activities observed in Hawaiian and Strombolian eruptions.

Moving bubbles drive flow around them and make near bubbles deform. In Manga and Stone (1995), they reported that the deformed bubbles attract near bubbles due to their hydrodynamic interaction. The attracting effect significantly changes coalescence dynamics but there are no theoretical models to predict their behavior.

Firstly, we drive equations describing bubble trajectory based on the theory which deals with two-body interaction taking bubble deformation into account. The equations allow us to calculate the relative movement of two bubbles. We assume that the liquid surrounding bubbles is viscous fluid and the deformation of the bubbles is small enough.

Relative trajectory is controlled by two dimensionless parameters, bond number (the ratio of viscous force driven by buoyancy and surface tension) and the size ratio of the two bubbles. The viscosity of the liquid effect only changes the time scale but doesn’t change the coalescence behavior. The calculation by the equations can reproduce the two-bubble trajectories reported in Manga and Stone (1995). Almost the same equations have already been derived and solved in the same paper but contain some errors and failed to reproduce the experimental data.

Secondly, we determine the critical conditions whether two bubbles coalesce or not. We have the critical initial separation as a function of bond number and size ratio of two bubbles. Coalescence efficiency is directly calculated from the critical separation. We compare the results of our calculation with experimental data in which coalescence efficiency in terms of critical separation of as a function of size ratio (Kushner et al., 2001; Manga and Stone, 1995). Coalescence efficiency increases linearly with bond number and reaches a constant value. This is caused by effective deformation for the large bond number. Our results agree well with the experiments. For small bond number (small bubble size), the coalescence efficiency decreases with increasing the size contrast. For large bond number (large bubble size), the calculation gives larger efficiency than the experimental data. The discrepancy is because of a limit of the approximation. The coalescence efficiency nearly constants for the large bond number in the experiments. So, we can treat efficiency as a constant for large bond number.

Our simple model can reproduce such a complex attracting behavior reported in the previous experiments. With our new method, we can calculate the evolution of bubble size distribution including bubble coalescence driven by buoyancy. It is noteworthy that the bubble interaction with the deformation effect show quite different behavior from rigid spheres case. For instance, the coalescence efficiency for the larger bubbles (larger than 5mm in silicate melts) considerably 10 times larger than rigid spheres case.

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