The lifetime of bubbles

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A process that is of fundamental importance for bubbly suspensions is bubble coalescence, the process whereby the liquid film that separates adjacent bubbles ruptures, transforming two or more individual bubbles into a single bubble of larger size. We present new experimental results of film drainage caused by liquid expulsion due to gravitational forces, associated with the density difference between bubbles and surrounding liquid, as well as capillary forces arising due to changes in curvature of the interface between a bubble and surrounding liquid. In our experiments the liquid film is not stabilized by surfactants or impurities, rendering the boundaries of the liquid film fully mobile. Air bubbles were suspended beneath the free surface of a layer of PDMS. We measured the time for the liquid film surrounding the bubbles to drain until the time of rupture. To ensure the dynamic similarity to magmatic systems, our experiments are at small Reynolds number (Re < 1), so that inertial forces are negligible during film drainage. Consequently, film drainage is solely driven by gravitational and capillary forces, and balanced by viscous forces. The relative dynamics of film drainage is determined by the relative importance of gravitational to capillary forces, quantified by the Bond number, which spans five orders of magnitude in our experiments from Bo $\sim 10^{-3}$ to Bo $\sim 10^{2}$, with a transition between capillary and gravitationally dominated drainage at $Bo = 0.25$. We derive a scaling relation for the drainage time $t \sim Cln\delta_o / \delta_f \, \tau$, where C is an empirical constant (C ~10), δ_o is initial film thickness and δ_f is final thickness. At Bo < 0.25 the characteristic time is given by $\tau = \eta R/\sigma$, whereas it is $\tau = \eta / \Delta \rho g R$ for Bo > 0.25, where R is bubble radius, η is fluid viscosity, σ is surface tension and $\Delta \rho$ is density contrast between bubble and liquid. We find that our results are consistent with previously published empirical drainage times of bubbles in silicate melts. In contrast, prior formulations for film drainage, based on the assumption of immobile film boundaries, result in over-predictions of film drainage times by at least several orders of magnitude.