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The dynamics of bubble ascent in the bubble-slug transitional regime, an empirical correlation.

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Magmatic explosive eruptions are driven by the build-up of gas overpressure following volatile exsolution. The style of an eruption is governed by magma rheology and viscosity, allowing or impeding bubble rise, growth and/or coalescence. The relative ascent velocity of bubbles in magma is one of the main parameters driving and defining the style of volcanic eruptions. Consequently, the dynamics of bubble ascent has been widely studied both experimentally and theoretically. For the end-member cases of unconfined bubbles (bubble radius, $R_b \ll$ conduit radius, R_c), and slugs ($R_b \approx R_c$) a robust theoretical framework exists. However, the transitional regime of partially confined bubbles, where $0.1 < R_b / R_c < 1$, remains poorly understood.

Here, we use analogue experiments to quantify the ascent velocity of partially confined bubbles through Newtonian liquids in cylindrical pipes. The experiments are scaled to cover the range of expected conditions in a volcanic scenario. Three transparent, Plexiglas pipes of different radii (R_c = 16.5, 33, and 50 mm) were filled with liquids of three different viscosities (0.06 – 53 Pa s) and densities (915 – 1438 kg/m^3). A syringe was used to inject a determined volume of air, and the subsequent bubble rise was filmed. Via image analysis techniques, the bubble's diameter and ascent velocity were measured. In the limits of low and high radius ratio, our measured velocities agree with previous results for unconfined and slug regimes. In the transitional regime, these end member cases are linked by a smooth, nonlinear relationship, which depends systematically on the inverse viscosity: at high inverse viscosities bubble velocity approaches the slug value at lower radius ratio.

Experimental results are compared with numerical results obtained using a two-phase incompressible fluid model, solved using a volume of fluid (VOF) method from the OpenFoam suite. After the numerical model was validated by experimental data, it is used to simulate conditions that are challenging to achieve experimentally. By the combination of both analogue experiments and numerical modelling, we cover the full range of conditions expected in the volcanic system. Based on numerical and experimental results, we present empirical relationships for ascent velocity of bubbles in cylindrical pipes, scaled to the volcanic case. These relationships can be used to provide a better understanding of bubble ascent dynamics in the transitional regime between unconfined bubble ascent and slug flow.