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Bubble Rupture in a Vibrated Liquid Under Microgravity

The response of an air bubble surrounded by a liquid in a sealed cell submitted to vibrations was investigated experimentally under microgravity conditions and compared to experiments under normal gravity conditions. As in normal gravity [1], it was observed that the bubble split into smaller parts when the acceleration of the vibrations reached a threshold. This threshold in microgravity is substantially smaller than that in normal gravity. Experimental results are presented in terms of an acceleration based Bond number which has been found to characterize the bubble behaviour in the laboratory experiments [1].

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Introduction

The bubbles play an important role in a wide range of geophysical and industrial processes [2–4] and the control of bubble size is of primary importance in many practical applications. An elegant method was proposed by Zoueshtiagh *et al.* [1] which consists of breaking up a bubble by submitting it to vertical vibrations. The authors carried out experiments under normal gravity conditions and showed that the vertical vibrations of a sealed cell containing a large air bubble (~4 ml) in a liquid of small viscosity could "uniformly" split the bubble to smaller pieces. The break-up threshold was found to occur at a constant acceleration of around G, where G denotes gravitational acceleration (981 $\mathrm{cm\,s^{-2}}$). It was also found that a Bond number Bo based on the acceleration of the cell containing the bubble characterized that threshold:

$$\mathrm{Bo} = \frac{D}{2l_c} = \frac{D}{2}\sqrt{\frac{\Delta\rho A(2\pi f)^2}{\gamma}} \qquad (1)$$

where D is the volume equivalent diameter of the bubble defined by $D=(6V/\pi)^{1/3}$ for a bubble of a volume V. l_c is a capillary length based on the acceleration of the cell and is given by $l_c=(\gamma/\Delta\rho A(2\pi f)^2)^{1/2}$. γ is the surface tension, $\Delta\rho$ the density difference between air and liquid, A and f the amplitude and frequency of the cell, respectively. Here, we present the break-up thresholds of a bubble in microgravity obtained by experiments in parabolic flights and compare them with the results on ground.

Experimental

The setup consists of a liquid-filled rectangular cell which contains an air bubble (V=3 ml). The cell has an inner dimension 6×8×6 cm. All experiments were performed at a room temperature ~25°C. The cell is vibrated along a vertical axis in a sinusoidal manner by a computer controlled servomotor. The system enables frequencies $0.1 \leq f \leq 3.5$ Hz and amplitudes $0.5 \leq A \leq 11$ cm. Bubble behaviour is observed with a high speed camera (120 images per second) in a view along the vibration axis as well as in a lateral view by a mirror equipped on a lateral wall of the cell at an angle of 45˚. To determine the bubble break-up threshold, we increase the frequency step-by-step with a small increment Δf, keeping the amplitude constant and observing whether any break-up occurs or not.

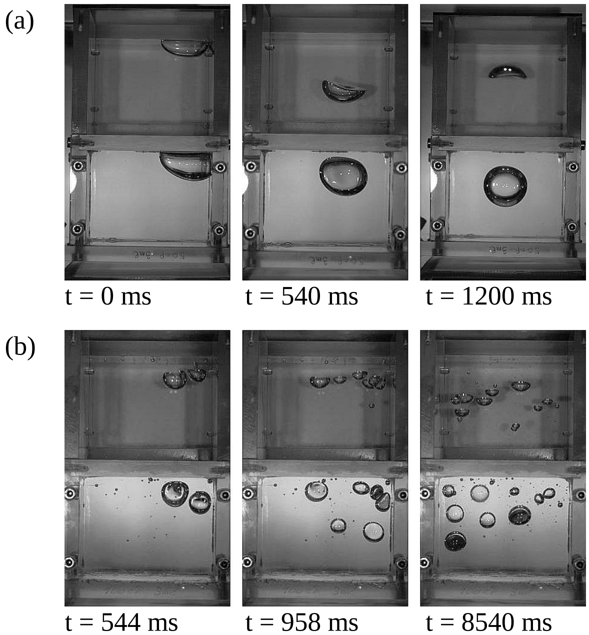

Fig. 1: Bubbles under vibrations (a) with no break-up (silicon oil 47V50, f=0.8 Hz, A=7.0 cm) and (b) with break-up (silicon oil 47V100, f=2.5 Hz, A=6.0 cm). t=0 corresponds to the start of vibrations. In each picture, the upper half part represents a side view obtained by reflection on the mirror and the lower half corresponds to a view along the vibration axis.

Results

Prior to each experiment, the bubble is squeezed on the upper wall of the cell (see the first picture in figure 1 (a)), as a consequence of 2*G* phase of a parabolic flight. After microgravity condition is established, the bubble becomes spherical and the cell is put under vibrations. The bubble is observed to undergo deformations (2nd and 3rd picture of figure 1 (a)). In figure 1, the vibration is below the break-up threshold. The bubble travels back and forth in the cell along the vibration axis, deforming its shape typically in the form of a spherical cap. When the frequency exceeds a critical value f_{cr}, the bubble is rapidly divided into small pieces (see figure 1 (b)). This division process continues until the bubbles size becomes small enough for the capillary pressure to counteract the breaking. Thereafter, the bubbles move back and forth in a shape of spherical caps without any further break-up.

In figure 2, the critical frequency f_{cr} of bubble break-up is shown. The frequency is normalized by the natural frequency f_N of a spherical bubble of the same volume: $f_N = (4\gamma/\pi\rho V)^{1/2}$ [5]. It is seen that f_{cr} is inversely proportional to $A^{1/2}$, in other words, that the break-up threshold is given by a constant acceleration. In figure 3, data obtained in micro- and normal gravity for liquids of different viscosities are shown in terms of the Bond number (1). The threshold of bubble break-up in microgravity is found to be substantially smaller than in normal gravity.

Conclusion

The break-up of a large bubble by vibrations under micro- and normal gravity conditions was investigated. In comparison to experiments on ground, a substantial drop in the critical acceleration (or critical Bond number) for the break-up was observed in microgravity. This suggests an easier break-up of bubbles in microgravity in spite of the reduction of squeezing (wall) effects on bubbles.

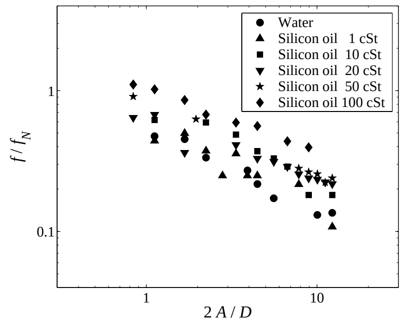

Fig. 2: Critical frequency of bubble break-up in microgravity. f_N is the natural frequency of a spherical bubble.

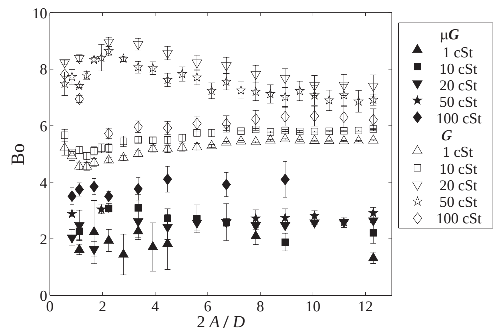

Fig. 3: Break-up thresholds in micro- and normal gravity.

Acknowledgements

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