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Sinking Bubbles

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"When a container of liquid (e.g. water) oscillates vertically it is possible that bubbles in the liquid move downwards instead of rising. Investigate the phenomenon".

Introduction

Usually, bubbles in a liquid rise due to density difference. The aim of this project was to explain the motion of sinking bubbles and research experimentally the conditions under which the formulae of earlier studies accurately describe the behavior of bubbles in oscillating liquids.

Approach

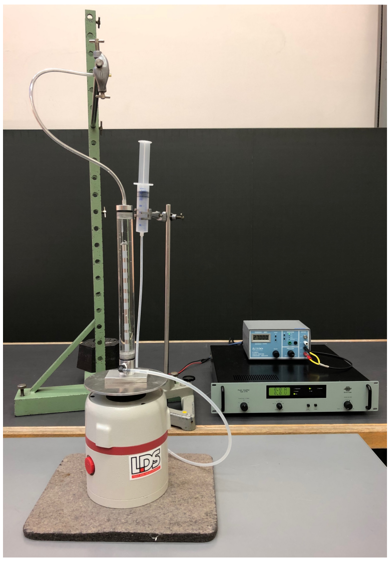

Figure 1: Picture of the set up. A cylindrical liquid column is driven harmonically by an oscillator. At the bottom of the column an opening provides a controlled inlet of air bubbles. A small hole in the top cap ensures ambient pressure.

Link to the video

Due to the driven oscillation induced by the excitor, the bubble's volume will periodically change size. One differentiates between two states of the bubble, the upwards and downwards acceleration. For high accelerations of the oscillator the bubble volume is significantly greater during the downwards acceleration, a net downward motion is thus observed.

Two types of experiments have been conducted. Firstly, for different frequencies and constant bubble position, the amplitude at which the bubbles would remain at the same depth (static motion) was measured. Secondly, the bubbles' motions were filmed with a high-speed camera and tracked. The experimental data have then been compared with the theory.

Shape of the Bubble

Large bubbles do not keep a spherical shape. As the equations of motion use a spherical approximation for the form of the bubble, the simulations must be less accurate for larger radii of the bubble. The deviation of the bubble's shape to a sphere was calculated using the ration of the radius to the capillary length.

equation used for the calculations $\frac{r}{\lambda_{cap}} = \sqrt{\frac{\rho g r^2}{\sigma}}$

In addition, one can consider the Reynolds number as a control parameter for the equations of motion.

formula of the Reynolds number $Re = \frac{v d \rho}{\eta}$

Equations of Motion

The static theory states that if the following equation equals 1, the bubbles will remain at a constant depth. For higher values, the bubbles will sink and vice-versa.

$$\boxed{1 = \frac{\rho \omega^4 A^2 h}{2 g \gamma p_0}}$$

The equation of motion found in literature was used to approximate the bubble's behavior in water.

$$\boxed{(m + m_0)\ddot{x} + \dot{m}_0 \dot{x} = -\frac{1}{2} C \rho A_B \dot{x}^2 + (\mathrm{m} - \rho V_b)(A\omega^2 \sin(\omega t) + g)}$$

The system in oil, however, is much more stable than the previous, an alternate equation of motion thus was created and subsequently used for the simulations in oil.

$$\boxed{\frac{d}{dt} m\dot{v} = -6\pi\eta \dot{x} r + (m - \rho V_b)(A\omega^2 \sin(\omega t) + g)}$$

Results

As it was found to be in good agreement with the experimental results, I validated the static theory.

Note that for the following diagrams. the x-axis represents the depth of the bubble. The blue line is the simulation calculated with the respective equation of motion and the orange dots are the experimental data points.

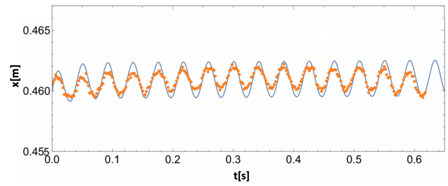

Figure 2: Motion of a bubble in a column of water. The Reynolds number of the motion is $Re = 1.9$.

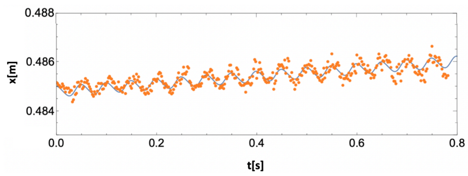

Figure 3: Motion of a sinking bubble in a vibrating column of oil. The Reynolds number of the motion is $Re = 0.01$.

Discussion

It has been observed that the more stable the system the more accurate the simulation becomes. The Reynolds number has been discovered to be a reasonable scale of stability. Low Reynolds numbers imply a better approximation of the motion and can be reached using small amplitudes of oscillation, small radii of the bubbles and high bubble depths.

Closing Remarks

To sum up, the formula giving the critical values of sinking for bubbles in a liquid has been validated for the first time. Experiments were conducted in water to verify the existing equation of motion. It was confirmed that the previous only works in a limited range, which was thereupon determined. To be able to predict more cases of sinking bubbles, experiments were conducted in oil. A modified equation of motion was established and from the experimental results one was able to confirm its accuracy for a broader range. The case in oil offers the advantage of greater stability, hence the use of simpler physics. To conclude, this paper gives an overview of the previous publications, accompanied by thorough qualitative results as well as an additional simple quantitative explanation to the non-trivial problem of sinking bubbles.