SWIMMING VIBRATED BUBBLES

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ABSTRACT

This experiment is about the motion of the gas bubble in vertical oscillating fluids. Bubbles which are made on the surface, sink instead of rising in a tank with low-viscosity liquid. When a container of liquid oscillates vertically it is possible that bubbles in the liquid move downwards instead of rising. This phenomenon was first observed in rockets engines. There are some pressure sensors in the rockets that make the parts of the rocket release in each layer of space. Because of the oscillation in the engine, sinking bubbles effect on the sensors and made the rocket to release its parts sooner and this makes the rocket explodes. This phenomenon has been investigated in this research.

1 Introduction

By shaking a container of liquid , it oscillates vertically and the bubbles in the liquid moves too. When the container moves up it makes the bubbles move down and visaversa . Bubble moves downward more than it moves up because of the smaller volume and smaller amount of water it needs to replace , when it wants to move down. These frequent phenomenon makes the bubble sinks.

2 Experimental Setup

A 50V speaker is connected to an amplifier (to empower the volume) and the amplifier is also connected to a smart device which has a frequency generating APP . A cylindrical glass with a plastic cap is used as the container. The container height and diameter is 10cm and 2cm, respectively. A slow motion camera, 240 frame /second is used to take the videos. Movements of the bubbles are tracked for collecting and analyzing data (Fig. 1)

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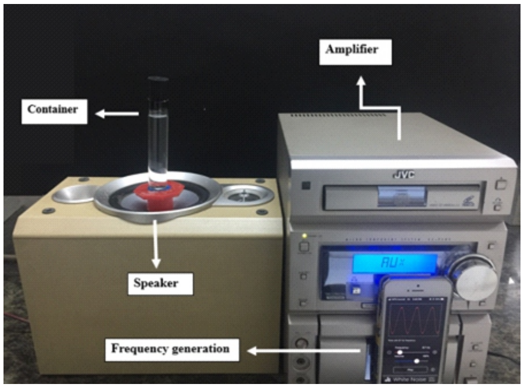


Fig.1: Experimental Setup

3 Theory and Model

3-1 Pressure and Acceleration

When fluids with different viscosity and density are next to each other there will be an instability in the system which causes the development of turbulence and makes the liquid grab the air and make some bubbles.

In order to investigate this phenomenon theoretically some conditions are considered .The fluid is considered incompressible and bubble is considered isothermal and the gas inside is considered as ideal gas . Because n, R and T are constant so in the 1st and 2nd situations in our system, S_1 and S_2, PV will be constant in the whole container (Eq.1).

$$PV{=}nRT \qquad P_T V_B = P_E V_{B_0}{=}const. \tag{1}$$

Pressure in S_1 is equal to external pressure and in S_2 is equal to pressure of the water over it and external pressure (Eq.2) (Fig.2).

$$P_t{=}P_E + \rho g h \tag{2}$$

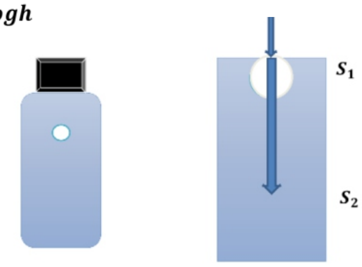


Fig.2: Position of bubble in two situations, S_1 and S_2

The movement of the speaker is sinusoidal so the place of the container and the acceleration which is applied by speaker can be calculated (Eq.3).

$$\ddot{x}{=}A\omega^2 \sin(\omega t) \tag{3}$$

The acceleration of the bubble is equal to g plus acceleration applied by speaker(Eq.4).

$$a_{bubble} = \quad g{+}A\omega^2 \sin(\omega t) \tag{4}$$

3-2 Volume of the Bubble

Volume of the bubble can be calculated according to the ideal gas (Eq.5).

$$P_T V_B = P_E V_{B_0}{=}const.$$
$$V_B{=}\frac{P_E V_{B_0}}{P_E{+}\rho x(g{+}A\omega^2 \sin(\omega t))} \tag{5}$$

According to Taylor's expansion this equation can be changed and simplified with two variables (Eq. 6 and 7).

Part 1: $\frac{\rho x(g+A\omega^{2}\sin(\omega t))}{P_E} \ll 1$ (6)

$$V_B = V_{B_0}\left(1 - \frac{\rho x g}{P_E}\left(1 + \frac{A\omega^2}{P_E}\sin\omega t\right)\right)$$

$$\gamma = \frac{\rho H_0 g}{p_e} \qquad W = \frac{A\omega^2}{g}$$

$$V_B = V_{B_0}\left(1 - \gamma\frac{X}{H_0} - \gamma\frac{X}{H_0} w \sin\omega t\right) \quad (7)$$

3-3 Forces Affecting on the Bubble

There are three forces affecting on the bubble; buoyant force, weight force and drag force (which is always in opposite direction of the movement)(Fig. 3). According to the Newton's Second Law we have (Eq. 8 and 9):

$$w - f_{(b)} + f_{(v)} = \frac{dp}{dt} \quad (8)$$

$$w = m(g + A\omega^2 \sin(\omega t))$$
$$f_b = \rho_l V_B (g + A\omega^2 \sin(\omega t))$$
$$f_V = -4R^2 \Psi(Re)\dot{x}^2 sgn(\dot{x})$$

$$m(g + A\omega^2 \sin(\omega t)) - \rho_l V_B (g + A\omega^2 \sin(\omega t)) + -4R^2 \Psi(Re)\dot{x}^2 sgn(\dot{x}) = \frac{dp}{dt}$$

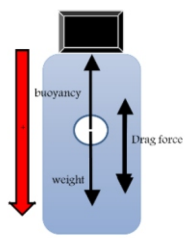


Fig. 3: Three forces affecting on the bubble

Because of the acceleration of the bubble inside the liquid, added mass should be considered (Eq.10 and 11) .

$$p = mv \qquad p = (m_b + m_a)\dot{x} \qquad m = m_b + m_a \quad (10)$$

$$m_a = \frac{v_b \rho_l}{2}$$

$$\frac{d((m_b + m_a)\dot{x})}{dt} = \dot{m}_a \dot{x} + (m_b + m_a)\ddot{x} \quad (11)$$

$$m(g + A\omega^2 \sin(\omega t)) - \rho_l V_B (g + A\omega^2 \sin(\omega t)) + -4R^2 \varphi(Re)\dot{x}^2 sgn(\dot{x}) = \dot{m}_a \dot{x} + (m_b + m_a)\ddot{x}$$

By tracking the bubble its position and radius versus time are analyzed (Fig.4).

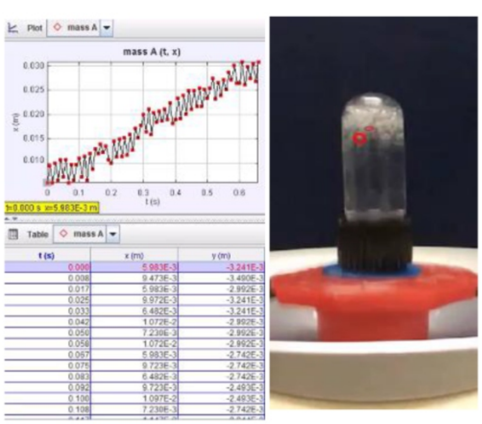
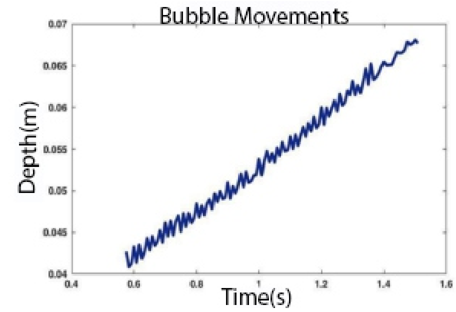


Fig. 4: Analyzing data by tracking the bubble and MATLAB software

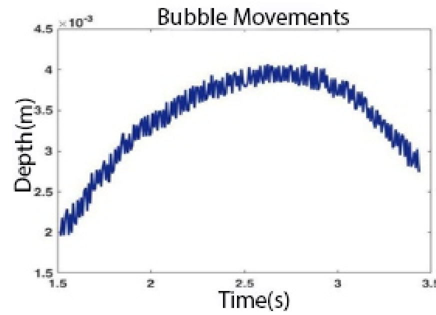
4 Experimental Procedures

4-1 Movement of the Bubble

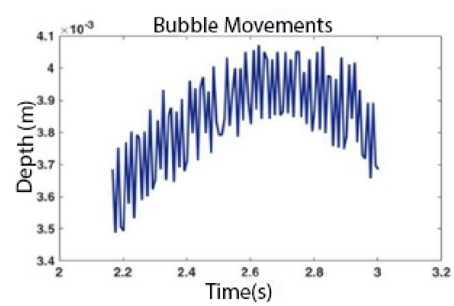
There are three kinds of movements of the sinking bubbles. Ones which go down and will be constant ones go down a little and trap near the initial depth and a floating ones which go down a little and then they return to the surface because they couldn't pass the initial depth (Fig. 5 a, b and c).



(a)



(b)

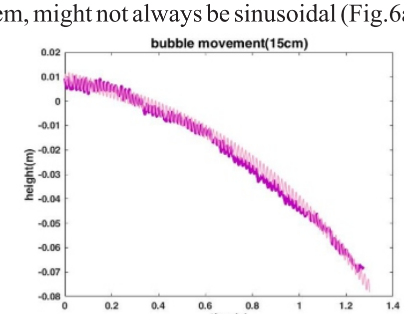


(c)

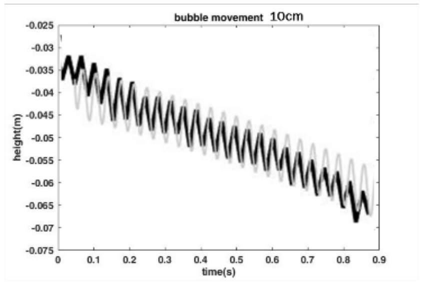
Fig. 5: Depth of the bubble per time , a) sinking bubble; b) floating bubble and c) constant bubble, respectively

4-2 Length of the Containers

In different lengths of container the behavior of bubbles are studied. The charts are not matched completely that is because of the turbulence in the system or amplifier is not perfect. That means the frequency which is applied to the system, might not always be sinusoidal (Fig.6a,b and c).



(a)



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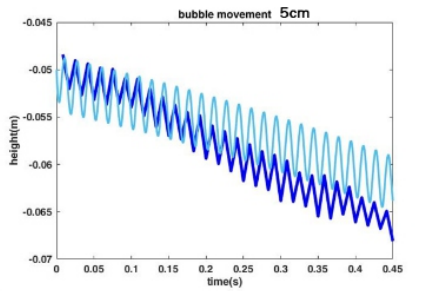
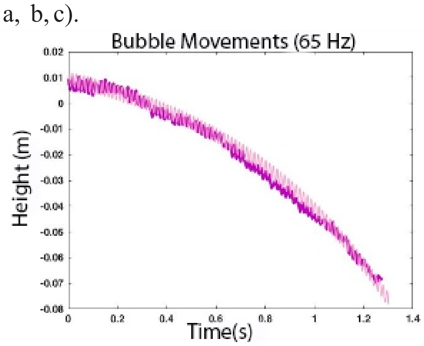


(c)

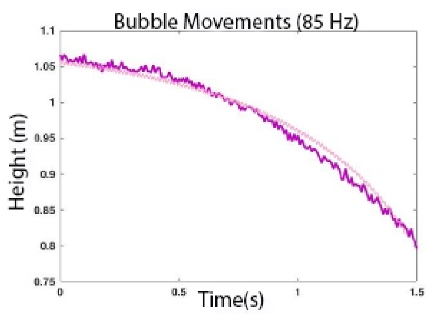
Fig. 6: Place of the bubble per time in containers with different lengths, a) 15 cm, b) 10 cm and c) 5 cm, receptively

4-3 Different Frequencies

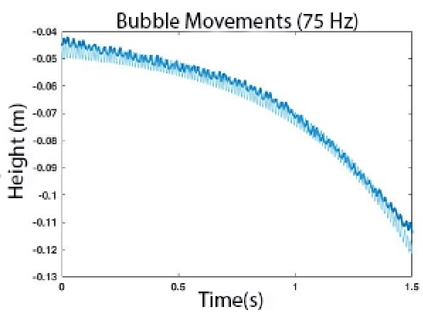
Place of the bubbles are studied in different frequencies (Fig. 7 a, b, c).



(a)



(b)

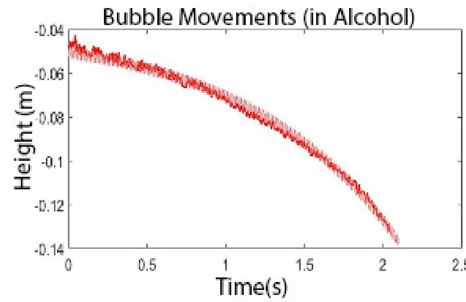


(c)

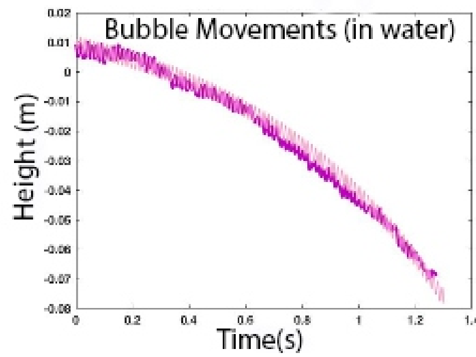
Fig. 7: Place of the bubble per time in different frequencies a) 65 Hz; b) 85 Hz and c) 75 Hz, receptively

4-4 Using Different Liquids inside the Container

The situations of bubbles are studied in different liquids such as water and alcohol (Fig.8 a and b).



(a)



(b)

Fig. 8: Place of the bubble per time in containers with different viscosities, a) alcohol; b) water, receptively

5 Conclusions

By investigating the forces affect on the bubbles, differential equation was solved then we compared three kinds of movements of the bubbles according to four parameters .

- By comparing different frequencies in our experiment, it is clear that, in an specific range of frequency the bubbles can sink (Fig. 9).

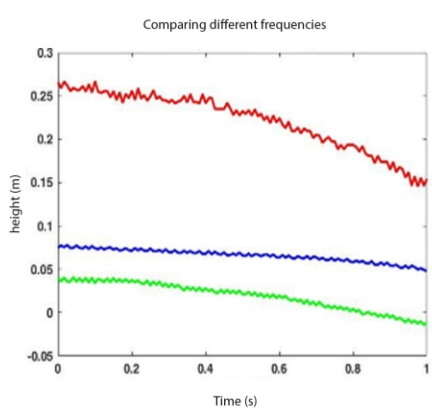


Fig. 9: Place of the bubble per time (comparing frequencies)

- As much as the viscosity and density of the liquid is lower the bubbles can move easier so it will sink sooner. So bubbles sank sooner in alcohol than water (Fig. 10).

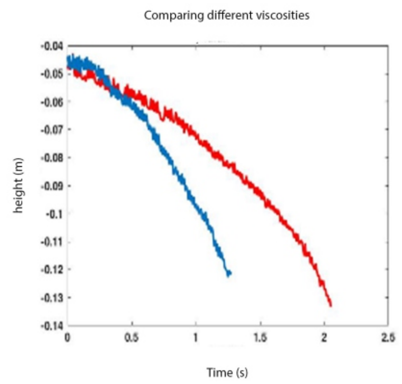


Fig. 10: Place of the bubble per time (comparing viscosities)

- As much as the container is shorter there is shorter distance in order to sink the bubble so it will sink sooner in 5cm than 10cm (Fig.11).

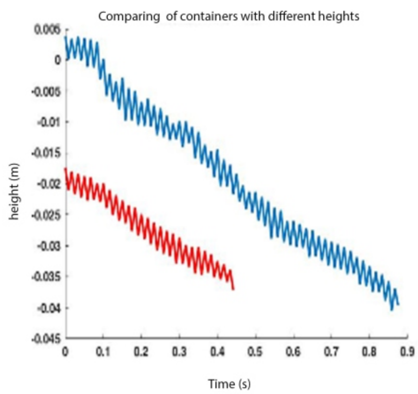


Fig. 11: Place of the bubble per time (comparing different containers)

- As much as the volume of the bubble is bigger, when it is made, the difference between added mass when it moves up and down will be more and it can be compressed more (Fig.12).

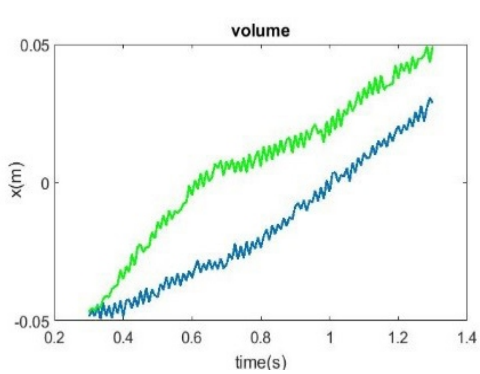


Fig. 12: Place of the bubble per time (comparing volumes)

In order to prevent the explosion of rockets some perforated cover plates can be used to increase the surface tension so bubbles will stick and won't affect on the pressure sensors . Another solution is that we can use a liquid with higher density and viscosity.

An application for this phenomenon is that we can use a gas solvent and a fluid with some resolvable in a container. It is oscillated then this bubbles will separate the particles from liquid. In some industries in order to separate particles from liquid they blow the bubbles but with this set up we don't need to blow (Fig.13). This set up can be used in different industries.

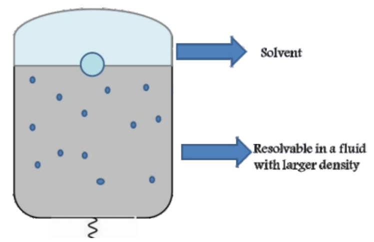


Fig. 13: An application for this phenomenon to separate the particles from liquid

References

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