Oscillations of Bouncing Soap Bubbles

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***Abstract*—Soap bubbles are toy models of microfluidics systems. It is found that adding glycerol, $C_3H_5(OH)_3$, into bubble solution stabilizes the bubble and extends its existence time. This project is to investigate the harmonic behavior of bouncing soap bubbles as well as the relationship between varying concentrations of glycerol in bubble solution and the frequencies of their oscillations. The experimental concentrations of glycerol by mass in 5% self-made bubble solutions are 0.0%, 11.8%, 16.7%, 21.1%, 25.0%. The falling process of bubbles after bouncing off a cotton surface is captured by high-speed camera and analyzed frame by frame using software ImageJ. The bubble on each frame is fitted into an ellipse and its Roundness - defined as minor to major ratio - is recorded and plotted into graphs. Besides observation from pictures, Fast Fourier Transformation (FFT) is performed to obtain frequencies of oscillations. Later we concluded that as the bubble falls from the acme after bouncing, the periodic roundness against time consists of multiple components. The observed period is always reflected by one of the peaks on corresponding FFT graph, but may not be the first peak. It means that the most observable period of oscillation by eye may not always be the dominant period shown by FFT graphs. We also found that the frequency of the oscillation reaches maximum at glycerol concentration of 16.7%.**

Keywords: Microfluidics, oscillation, soap bubbles, glycerol

I. INTRODUCTION

Confined fluids exhibiting surface oscillations are also found in industrial and technological processing. Such oscillations are versatile; one of potential applications is Lab-On-a-Chip[1]. For example, pinched flow coupled shear-modulated inertial microfluidics are used for blood cell separation[2].

Soap bubbles are controllable toy models for microfluidics system[3]. Understanding the physics of bubbles is important for a variety of scientific fields, from cosmology to foam science[4]. However, the oscillation of soap bubbles is a daily yet poorly understood phenomenon. This research is an example of a careful experiment clarifying a simple problem.

Oscillation frequencies of a bubble immediately after being bounced off a surface are comparatively low, rendering experimental observation and precise recording highly viable with a high speed camera.

In this research, glycerol $C_3H_5(OH)_3$ is an additive to reduce the surface tension of soap bubbles. Glycerol also forms weak bonds with the water molecules and slows down evaporation of water layer, thus improving the lifespan and durability of the bubble.

The project is to investigate the harmonic behavior of bouncing soap bubbles and the effect of varying concentrations of glycerol in bubble solution on their oscillation frequencies.

II. METHODS AND MATERIALS

A. *Preparing bubble solutions*

Bubble solution comprises 5.0 g of detergent MAMA LEMON and 95.0 g water, both weighted using electronic balance. Five portions of 15 g bubble solution were extracted for every set of experiment. 0.0g, 2.0g, 3.0g, 4.0g, 5.0g of glycerol was added to the 5% solution portions respectively, in order to create solutions with varying glycerol concentrations of 0.0%, 11.8%, 16.7%, 21.1%, 25.0%.

B. *Schematic set-up and producing bubbles*

As shown on Fig. 1, bubbles in the radius range of 3.5 $\pm$ 0.5 cm were produced in a controlled fashion from homogeneous solution, by a generator[5].

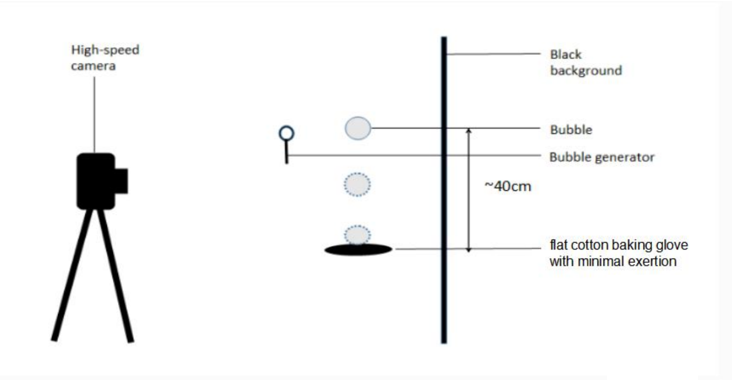


Figure 1. Schematic set-up of the experiment

Air enclosed by thin films (the thickness was estimated from reflective colors to be less than 1x10^{-6} m) in bubbles was of the similar density as that in atmosphere. A density of air of 1.2 kg/m^3 and a viscosity of 17.1x10^{-3} kgm^{-1}s^{-1} were assumed. The equilibrium state of the bubble is approximately spherical[6].

C. *Bouncing the bubbles and videoing the process*

Each bubble was allowed to fall by about 40 cm and oscillate freely in air before being bounced off a flat cotton baking glove gently with minimal exertion. The bubbles are allowed to oscillate freely in air as it traverses upwards, reaches a peak and then downwards. The phenomenon is captured by a high speed camera, operating at 240 frames per second (fps).

D. *Data analysis*

Videos for analysis were selected on the basis of their image quality and their vertical travel path i.e. we select bubbles that fall vertically. Two sets of data for each glycerol concentration were analyzed frame by frame using software ImageJ. Measurements such as minor, major, area, roundness of bubbles were computed, recorded and plotted against time. Since the frames demonstrate only two-dimension of the three-dimensional motion, the orientation of major and minor axis was varying, therefore the minor to major ratio measurements are prioritized. Fast Fourier transformation (FFT) was performed to obtain frequencies of oscillations. The FFT size here is 512. (i.e. the the number of bins used for dividing the window into equal strips or the frequency resolution, is 512)

III. Results and Discussion

Fig. 2 below shows the fitting process for 6 sample frames.

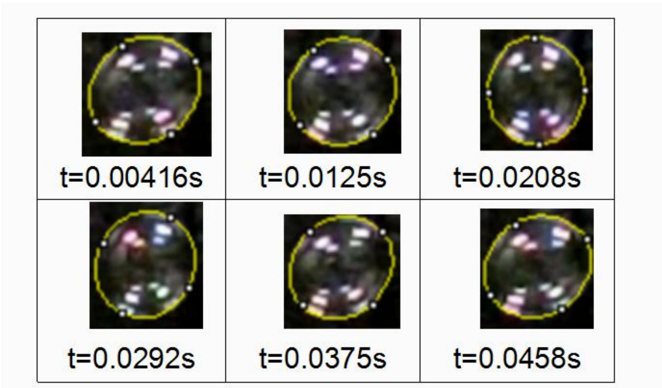
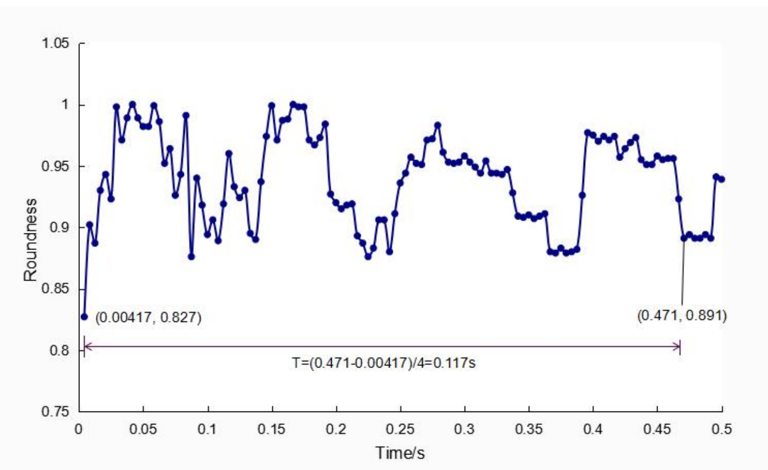


Figure 2. Screen-shots of the bubbles in ImageJ

A. *Observation for Roundness Graph*

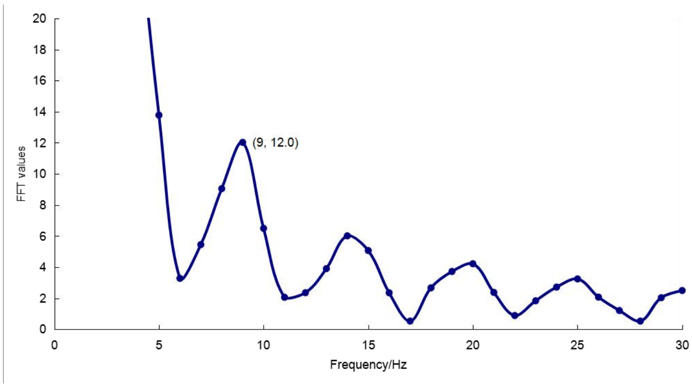
Graphs (Graph 1~4) of roundness against time are plotted for every experimental concentration. Periodic pattern is observed, which consists of multiple modes of oscillation that can be further broken down based on Fourier Analysis.



Graph1. Roundness against time with 0.0% glycerol: the most observable period T =0.117±0.004s

B. *Observation for FFT Graph*

Fast Fourier Transform (FFT) is used to convert graphs from time domain to frequency domain, thus helping us to pick out possible modes of vibration from the time series data, verifying the observed period. Three major peaks on FFT plot are taken to find the dominant frequencies for comparison. The aim is to verify the observed period from Roundness graphs.



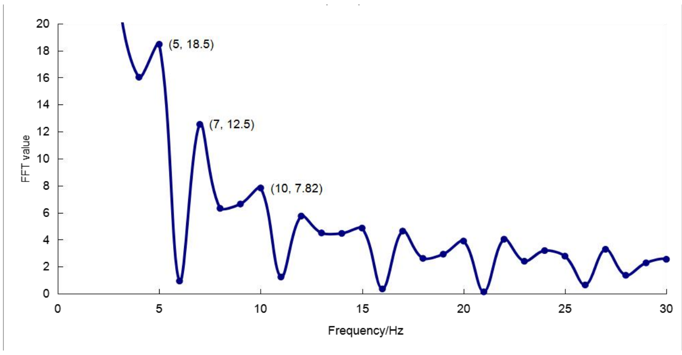
Graph2. FFT values on "roundness against time" at glycerol concentration 0.0%

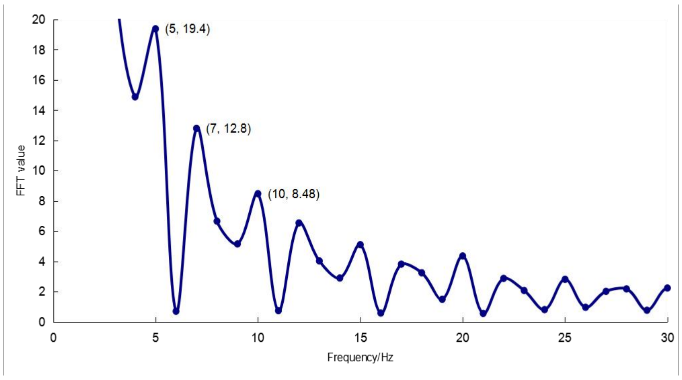
For example, at glycerol concentration of 0.0%, the first peak occurs at frequency= 9 Hz. Thus the period is 0.111 s (3s.f). Similar calculation is carried out for other glycerol concentrations and Table 1 shows the observed periods for every glycerol concentration.

Table1. Observed periods for different glycerol concentrations

Concentration of glycerol	Observed period from Roundness graph/s
0.0%	0.117
11.8%	0.100
16.7%	0.0833
21.1%	0.0958
25.0%	0.108

One thing to be highlighted is FFT graph at glycerol concentration 11.8%, which shows a slightly different trend. Yet the coincidence of the two analyzed sets at 11.8% proves reproducibility of the data (Graph 3&4).





Graph3&4. FFT values on "roundness against time" at glycerol concentration 11.8% (Set A and Set B)

The first peak at 5, giving period of 0.2s. This deviates largely from the observed period in Roundness for the same concentration. The third peak of FFT graph, instead, gives 0.100s, a value closer to observed period. This shows that the observed period is, while always reflected by one of the peaks on corresponding FFT graph, not necessarily to be the first peak. It means that the most observable period of oscillation by eye may not always be the dominant period shown by FFT graphs.

C. *Comparison of Observed periods on both types of graphs*

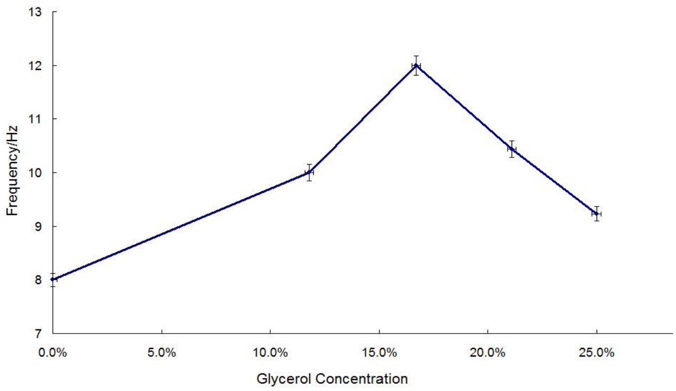
TABLE2. PERIODS FOR DIFFERENT GLYCEROL CONCENTRATIONS

Concentration of glycerol	**Observed period from Roundness graph/s**	**Calculated period from FFT graph/s**
0.0%	0.117	0.111
11.8%	0.100	0.100
16.7%	0.0833	0.0769
21.1%	0.0958	0.0909
25.0%	0.108	0.100

As we can see from Table 2 which shows the comparison of periods obtained from both types of graphs for different glycerol concentrations almost agree with each other, though the most observable period may not be the dominant period shown by FFT graphs.

D. *Relation between frequency and glycerol concentration*

The optimal concentration to achieve the highest frequency is about 16.7%. This means the bubble is the most 'stiff' when concentration of glycerol in bubble solution is at 16.7%. More data (at glycerol concentration of 12.0%-20%) is required to obtain the exact value, which is not the main focus of this project.



Graph5. Frequency against glycerol concentration in bubble solution

These experimental results provides a basis for future research. The values tell us that at any time microfluidics systems are employed to perform tasks whereby the frequency of oscillation needs to be controlled, we can achieve it through adding varying concentrations of additive such as glycerol. Thus the data obtained are of practical usefulness.

IV. Conclusion and Future Work

Here we reach the three main conclusions of this research:

1. The frequency increases with the concentration of glycerol within the range of 0.0%~17.0%. However frequency's behavior deviates from the hypothesis by presenting a maximal value at glycerol concentration of about 16.7% and decreases when further more glycerol is added.

2. As the bubble falls from the acme after bouncing, the periodic graph of roundness consists of multiple components, which can be broken down with a Fast Fourier Transform.

3. The most observable period of oscillation by eye may not always be the dominant period shown by FFT graphs (i.e. 1st peak)

We recognize that the use of ImageJ for parameter fitting involves a degree of estimation. For a more in-depth understanding on the mechanism. we can:

1) use laser-induced bubbles;

2) test the stiffness of bubbles in relation to glycerol concentration and compute effective spring constant to verify the relation[7].

3) try smaller intervals in concentrations (vary concentration instead of mass of glycerol)

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