Lifetime of the Antibubbles: Influence of the Surface Tension

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Abstract

An antibubble is a special structure that is produced in liquid and is coated by a gas film. The lifetime of the antibubbles is related to temperature, pressure, electrolyte concentration, viscosity and so on. Besides, surface tension of the solution is one of the important factors. The experimental results indicate that the lifetime of the antibubble varies with the surface tension of the solution.

Keywords

Antibubbles, Surface tension, Lifetime.

1. Introduction

Antibubble has a special structure which is produced in the solution and wrapped by an air film. The structure of the antibubble is opposite to that of the bubble.

In 1932, W. Hughes found the existence of antibubbles, but it did not cause the researchers' attention at once [1]. In 2003, S. Dorbolo applied the high-speed camera to the research of the antibubble and recorded the process of the generation and burst of the antibubble [2]. In the same year, S. Dorbolo figured out the antibubble would burst immediately when the pressure around the antibubble rose to the "critical pressure" [3]. Since then, the research of the antibubble attracted the attention of researchers globally.

In 2005, S. Dorbolo found that, due to the differential pressure between the up and down of the antibubble, the bottom of the air film would become thinner and thinner. Eventually, the antibubble failed down [4].

In 2009, S. Dorbolo verified that the lifetime of the antibubble would become longer in the vortex [5]. In 2013, through experiments, Ji An found that the higher the viscosity of the solution was, the longer the lifetime of the antibubble was [6] and the higher the pressure of the environment was, the shorter the lifetime of the antibubble was [7] and the higher the electrolyte concentration was, the longer the lifetime of the antibubble was [8]. In the same year, Jun Zou put forward the factors that affect the process of antibubbles burst [9].

In 2014, S. Dorbolo researched the effect of solution-dissolved air saturation on the lifetime of the antibubble and found that the more air dissolved in the solution, the longer the lifetime of the antibubble was [10]. In 2015, Denis Nikolaevich Sob'yanin established a rupture model of antibubbles [11]. In 2016, Lixin Bai developed a new method for preparing antibubbles [12].

Due to the special structure of antibubbles and the particularity of the process of its generation, the study of antibubbles will be of great significance for fields of chemical engineering, medicine, ship drag reduction, hydraulic, fluid machinery and so on. In 2013, Albert T. Poortinga found that the production of micro antibubbles [13] with good stability (lifetimes of at least an hour) can laid the foundation for targeted drug delivery in medical. The generation and rupture of antibubbles are closely related to surface tension of the solution. So cavitation can be effectively avoided by studying the conditions for producing antibubbles and requirement of its lifetime, and destroying environment of the antibubble production in fluid machinery. However, no work has been dedicated to the influence of surface tension on the lifetime of the antibubble. So this article just fills this gap.

Surfactant is one of the prerequisites in the generation of antibubbles, and the direct purpose of adding surfactant is to reduce the surface tension of the solution so that the liquid surface can form a suspension droplet. And then the suspension droplet is "pushed" into the solution by jet acceleration to form an antibubble finally.

Currently, most researchers use commercial detergent as a solute for the preparation of antibubbles. The experiment found that, because of wide distribution of surfactant components in commercialdetergent, the relationship between active agent concentration and the lifetime of antibubbles cannot be truly expressed by simply using the volume concentration of detergent. Therefore, by measuring the surface tension of the solution with different volume concentrations, this study found out the relationship between the lifetime of antibubbles and the surface tension of the solution and provided an experimental basis for exploring the theory of antibubbles stability.

2. Experimental description

2.1 Surface tension measurement method

This experiment adopts the capillary rise method [14] for measuring the surface tension of the different solutions.

The additional pulling force produced by the surface tension is upward, so that the liquid surface in the capillary rises, when the gravity and surface tension of the liquid column become balanced:

$$2\pi r\sigma\cos\theta = \pi r^2(\rho_l - \rho_g)gh \tag{1}$$

Transformation (1) can be obtained:

$$\sigma = \frac{(\rho_l - \rho_g)\,\mathrm{ghr}}{2cos\theta} \tag{2}$$

In formula (2): σ—surface tension of the liquid; r—inner diameter of capillary; θ—contact angle; ρ_l and ρ_g—density of liquids and gases; h—height of liquid column; g—local gravity acceleration. This experiment uses a transparent glass tube; the tube can be completely wetted by the liquid, so the θ approximation is zero degrees. And it is difficult to determine the reference liquid level when measuring the height of the liquid column with a single capillary. Therefore, two capillaries with internal diameters of 0.4 mm and 0.5 mm were used to measure and calculate Δh in this experiment. The formula (2) can be optimized to:

$$\sigma = \frac{(\rho_L - \rho_g)}{2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)}\left(\Delta h + \frac{r_1}{3} - \frac{r_2}{3}\right) \tag{3}$$

In formula (3): ρ_L is the density of the solution; ρ_g is the density of the air; r_1 is the inner diameter of the larger diameter capillary; r_2 is the inner diameter of the smaller diameter capillary; Δh is the height difference between two capillaries.

Table 1 Five solutions components and theirs surface tension

No.	Solution volume (Active volume concentration)	Surface Tension（mN/m）
Trial1	5L（0.1%）	47
Trial2	5L（0.3%）	35
Trial3	5L（0.5%）	34
Trial4	5L（0.7%）	32
Trial5	5L（0.9%）	29

To avoid measurement errors, ten groups of data were measured for surface tension of each solution. The actual value of Δh was calculated by image processing to obtain the average value of Δh. Different solution concentrations and the corresponding surface tension of solution are shown in the Table 1. According to the properties of surfactant, before the concentration of surfactant solution reaches the critical micelle concentration, the surface tension decreases with the increase of surfactant concentration; while after that, the surface tension of the solution no longer decreases with the increase of surfactant concentration.

2.2 Antibubbles preparation and lifetime measurement

The instrument used in the experiment is rectangular transparent glass cylinder, in which five kinds of solution with volume concentration as shown in Table 1 are respectively disposed. The laboratory temperature is stable at 15℃, and the solution temperature is about 14℃. The solution should be fully stirred and placed for more than half an hour, so that the air fully dissolved in water to achieve dynamic equilibrium (Eliminated the influence of temperature difference between air and solution at the same time).

The method of generating antibubble in this experiment is the incident flow. At 45 degrees incidence angle, the jet is produced by the washing ear ball. Firstly, let the jet flow slowly, form suspension droplets on the surface of the solution, and then the flow rate is instantly increased, so that the film-wrapped droplets sink into the solution to form an antibubble.

3. Literature References

The relationship between the lifetime of the antibubble in each solution and the diameter of the antibubble is shown in Figure 1 to Figure 5.

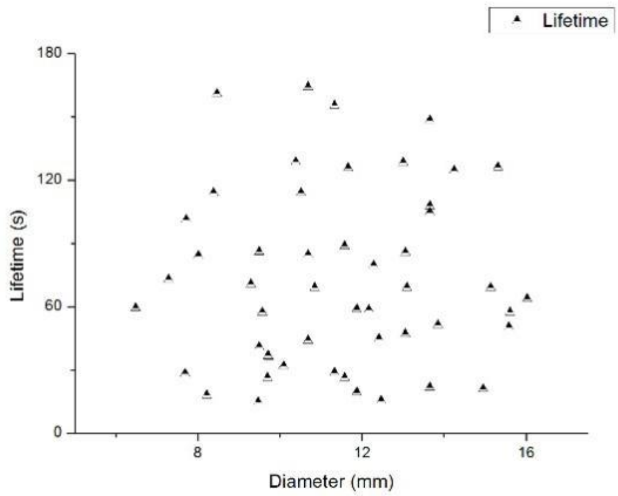

Fig. 1 Relationship between lifetime and diameters of antibubbles in 0.1% volume concentration solution

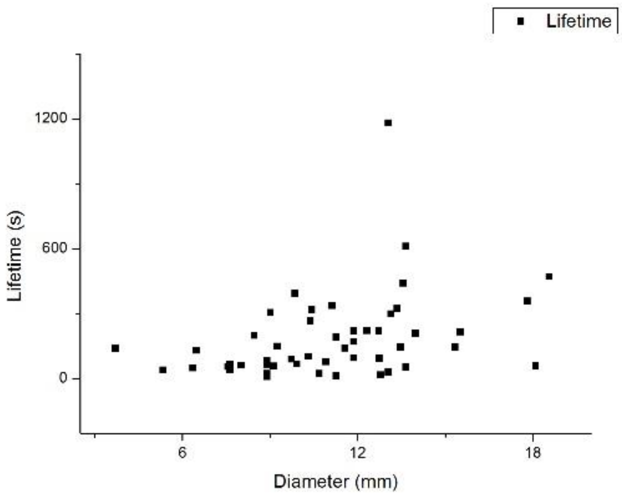

Fig. 2 Relationship between lifetime and diameters of antibubbles in 0.3% volume concentration solution

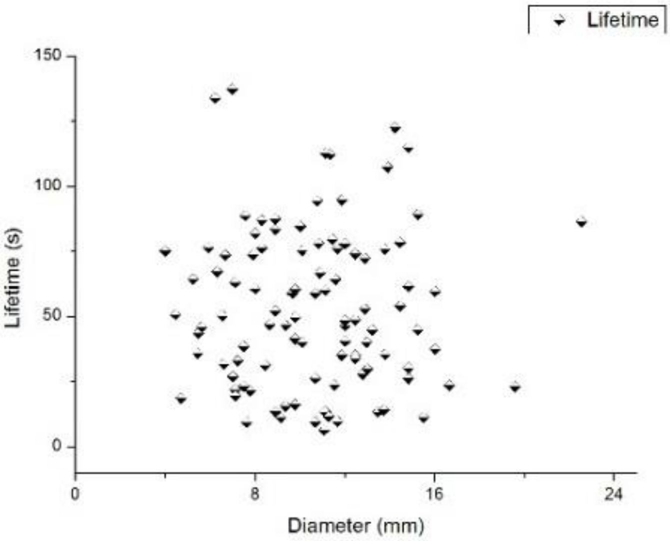

Fig. 3 Relationship between lifetime and diameters of antibubbles in 0.5% volume concentration solution

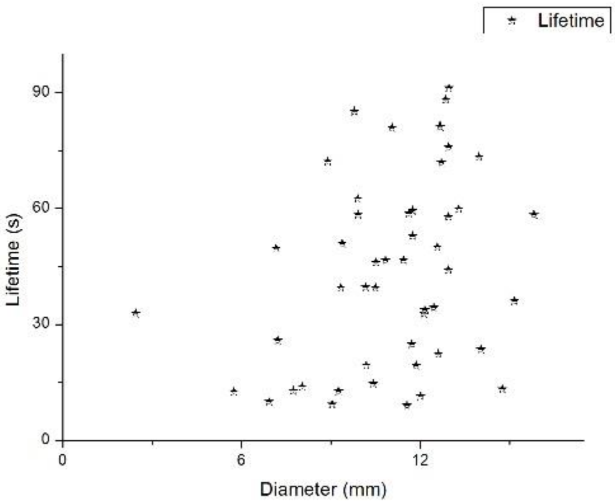

Fig. 4 Relationship between lifetime and diameters of antibubbles in 0.7% volume concentration solution

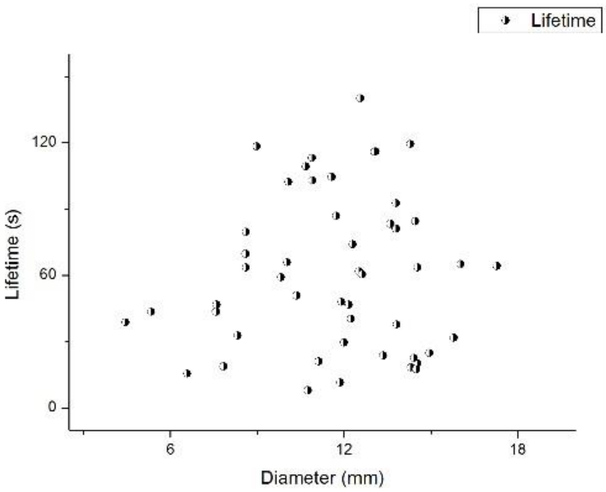

Fig. 5 Relationship between lifetime and diameters of antibubbles in 0.9% volume concentration solution

From Figure 1 to Figure 5, it can be seen that as diameters of antibubbles changes, the lifetime of the antibubble is discretely distributed. So the lifetime of antibubble is not directly related to the diameter of antibubble.

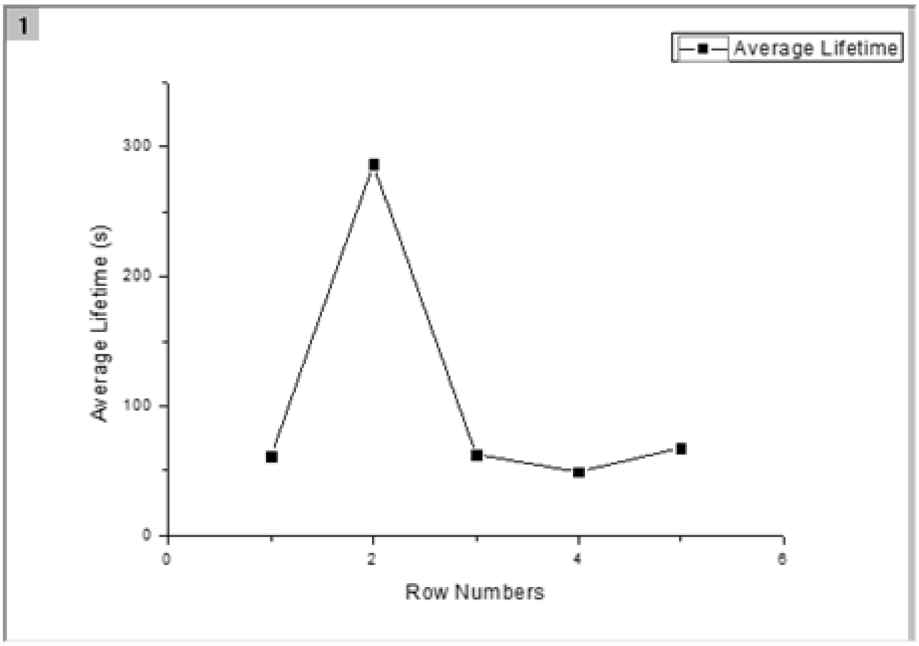

Fig. 6 shows the trend of average lifetime of different solutions

The antibubbles average lifetime of the five solutions were 61.16s, 286.29s, 62.70s, 49.14s, 67.75s, 54.93s, the trend of lifetime changes with the decrease of surface tension is shown in Figure 6. As the surface tension of the solution decreases, the lifetime of the antibubbles gradually increases. After the surface tension decreases to 34mN/m, the lifetime of the antibubble no longer changes obviously with the change of the surface tension.

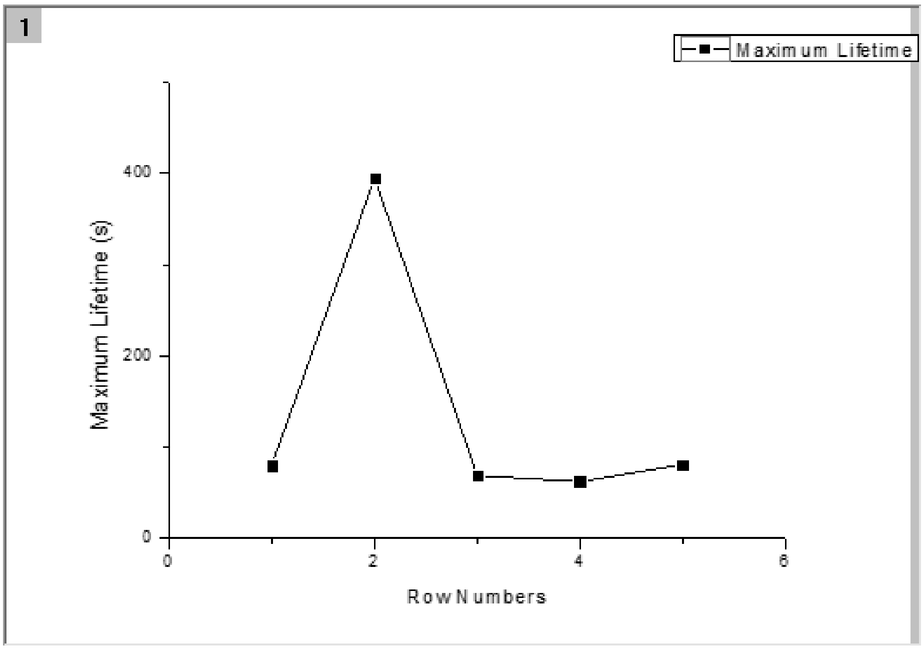

Fig. 7 Maximum lifetime trend antibubbles in different solution

As shown in Figure 7, the trend of the maximum lifetime of antibubbles and their average lifetime in five solutions are consistent the trend of the average lifetime.

As shown in Figure 8, according to the experimental data, the relationship between the change of the antibubble lifetime and the surface tension of the solution was fitted.

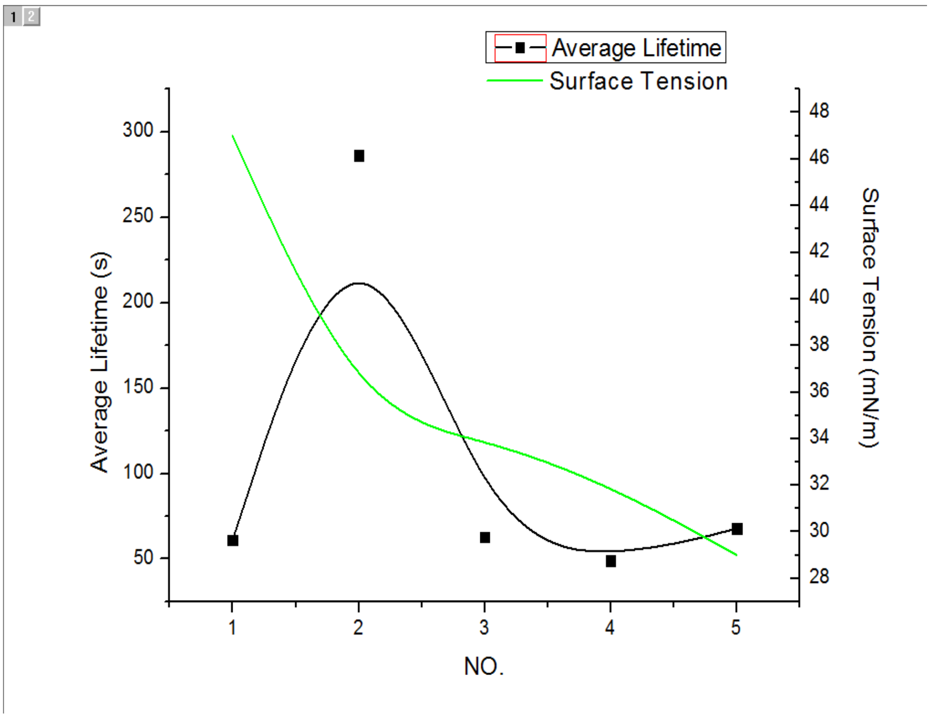

Fig. 8 the changing trend between the surface tension of the solution and the average lifetime of antibubbles

4. Conclusion

(1) The lifetime of antibubbles is independent of its diameters;

(2) It is an essential condition for the preparation of antibubbles that reducing the surface tension of the solution. The larger the concentration of solution surfactant, the easier it is to prepare antibubbles;

(3) When the surface tension of the solution is in the range of 47-35mN/m, the lifetime of antibubbles gradually increased; When the surface tension of the solution is in the range of 35-34mN/m, the lifetime of antibubbles decreased gradually; When the surface tension of the solution is less than 34mN/m, the lifetime of antibubbles no longer changes with the surface tension.

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