Numerical Analysis and Experimental Research on the Water-based Bubble Nozzle Flow Model

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Abstract

The bubble formation speed of water-based bubbles and the distribution of bubble size are critical to its engineering application. This thesis starts from both experimental and theoretical aspects, and establishes a model around the bubble formation process and state change process of water-based bubbles, and performs numerical analysis and calculations. Through the self-made bubble generating device and with the help of high-speed camera and auxiliary analysis system, the experimental verification is carried out, and the results are relatively consistent. Experiments have found that the nozzle cross-sectional area and nozzle position have an important influence on the bubble generation time and size distribution.

Keywords: water-based bubbles, nozzles, numerical analysis, optoelectronic countermeasures.

1. Introduction

With the development of modern detection and guidance technology, dual-mode multi-mode guidance weapons have been widely used. In the field of optoelectronic countermeasures, there is an urgent need to develop new shielding and jamming technologies to deal with it. In recent years, some new interference technologies such as dual-mode decoy bombs that can effectively interfere with infrared and laser bands, infrared laser matching chaff, imaging false targets and combustible combined dual-mode shielding smoke screens have emerged [1-4]. It can interfere with two or three specific detection bands to form a certain effective shielding effect. But it still hasn't solved the problem of wide-band (at the same time effectively interfering with visible light, laser, infrared, millimeter wave, and centimeter wave signals). Compared with other optoelectronic countermeasures technology, military water-based air bubbles and atomized curtains have a wider effective interference band (effective interference to visible light, laser, infrared, millimeter wave, and centimeter wave signals), and it is non-toxic and pollution-free. It lasts for a long time and is a new type of passive photoelectric interference technology.

At present, the research on water-based bubble matting formula technology, bubble stability and matting performance and mechanism is relatively in-depth; but the bottleneck problem that restricts the rapid and controllable fogging of the engineering application of water-based bubbles and atomized curtain technology is still There is no effective solution [5]. Therefore, it is urgent to explore the bubble formation mechanism to solve the bubble formation speed and study the factors affecting the bubble formation performance to provide the necessary theoretical support for the engineering application of water-based bubbles.

2. Experiment Platform
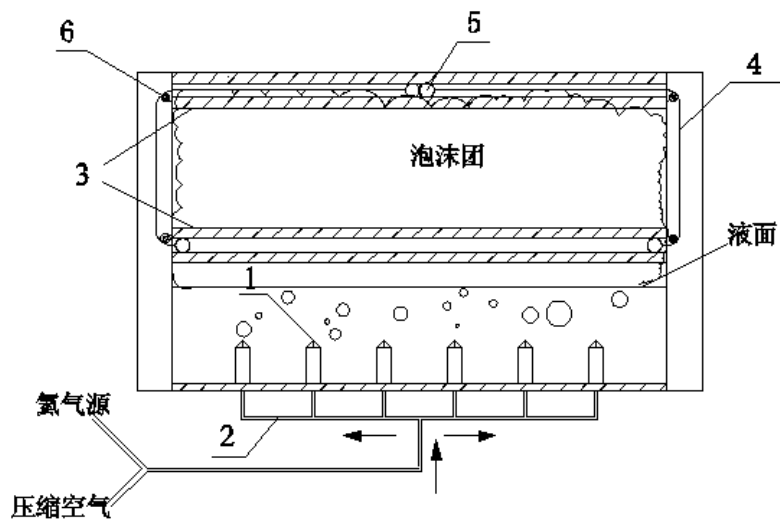
1. Air nozzle, 2. Air hose, 3. Cross bar, 4. Plastic film, 5. Aluminum long tube, 6. Small pulley

Figure 1. Principle diagram of water-based bubble experiment system

Figure 2. Nozzle of bubble generating device

The principle of the water-based bubble test bench system is shown in Figure 1. The matting foaming liquid is placed in a special container designed by ourselves, and the external structure size of the device is 0.8×0.6×0.5 (m). Several air distribution nozzles are arranged in a certain area under the liquid surface of the container, and the nozzles and the air source are connected by a hose. The helium source and compressed air are mixed in a specific ratio (to ensure the air-trapping performance of water-based bubbles) and then connected to the air distribution nozzle to prepare water-based bubbles for experiments. The helium gas source adopts the high-purity helium gas (14MPa) produced by Nanjing Yihe Company, and the compressed air is produced by the air compressor (maximum exhaust pressure 0.8MPa) produced by Beijing Unicol Compressor Co., Ltd., each is controlled by a flow valve The air intake ratio and speed are connected to the air distribution pipeline through the three-way.

Its working process is to input a specific proportion of mixed gas into the gas distribution pipeline through the set working parameters, and fill it into the foaming liquid through the nozzle, and form bubbles under the action of the hydrostatic pressure of the liquid phase outside the mixed gas, and the bubbles appear as a whole A relatively regular spherical shape. Because the initial pressure inside the bubble is much greater than the external pressure (atmospheric pressure), the bubble volume continues to increase. In this process, along with the interaction of the surrounding liquid phase, the bubble is no longer a regular spherical shape, but transformed into an ellipsoid. As time goes by, the ellipsoidal bubble rises from the nozzle. In this process, due to the interaction of the gas and liquid phase in the bubble and the interaction of the bubble and the bubble, the bubble continues to burst, deform, merge or aggregate. At the same time, the next batch of bubbles is regenerated at the nozzle and the cycle continues. After the bubbles rise to the liquid surface, due to the surface tension and the liquid bridging force, they gather on the liquid surface to form a cloud of bubbles. The nozzle of the bubble generating device is shown in Figure 2. During the preparation process, a high-speed camera (HG-100K high-speed digital camera, recorded at 250fps and 1000fps, respectively) was used to record the generation process and assist in the analysis of the bubble group size distribution, and the results were processed by a computer.

3. Numerical Simulation

In order to explore the bubble generation process and its laws, a bubble generating device model was established, and its life cycle was simulated with fluent. According to the state change of the mixed gas during the bubble generation process, the model was simplified for calculation purposes:

(1) In the whole state process, only the gas-liquid two-phase flow state is considered, and the role of the superfine powder functional additive in the liquid phase is ignored;

(2) The air flow velocity in the gas supply pipeline is small (about 1m/s), the pressure distribution is uniform, the mixed gas is ideal and complete, and the laminar flow model is used;

(3) In the experiment, the nozzle is directly much smaller than the bubble diameter. For the convenience of calculation, it is regarded as a point source;

(4) Use the VOF model and adopt the simple pressure-velocity coupling algorithm widely used in engineering flow fields;

(5) Establish the equation of state for the bubble volume of the nozzle orifice, use Runge-Kutta methods to solve [6, 7], and draw the result into the corresponding graph after calculation. The liquid phase density is 1000kg/m3; the initial temperature of water is 298K; the atmospheric pressure is 1.01×105Pa;

(6) The nozzle outlet parameters are consistent with the bubble inlet parameters, assuming the gas isentropic flow, ignoring friction.

(a)
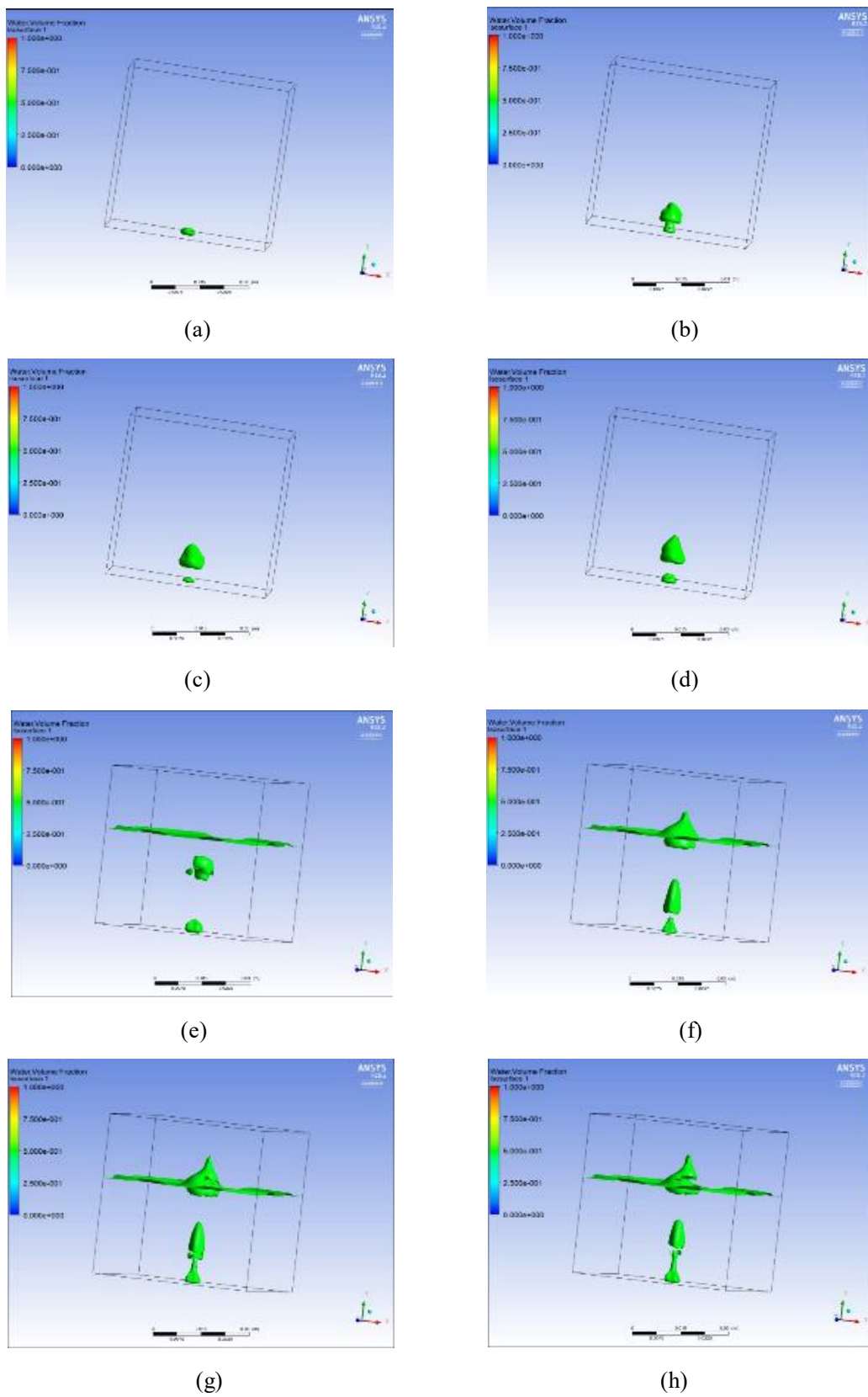
(b)

(c)

(d)

(e)

(f)

(g)

(h)

Figure 3. Several forms during the formation of water-based bubbles

4. Model Calculation Results and Verification

(1) The bubble generation process

The bubble formation theory believes that the bubble generation method is closely related to the nozzle flow rate. When the flow rate is low, the mixed gas enters the liquid phase, and a single bubble is formed at the nozzle; when the flow rate is high, the mixed gas enters the liquid phase as a continuous flow. After speed shearing, a series of bubble groups of different sizes are formed. In order to verify the bubble generation process, this model simulates the bubble generation process under low flow conditions.

After the mixed gas enters the liquid phase through the nozzle, the bubble volume increases rapidly due to the pressure difference between the inside and the outside and the continuous entry of gas. Due to the density difference between the two phases, the bubble rises. However, due to the bridging force at the lower part, a "tail" is formed (as shown in Figure 3(a)) and mushroom-shaped bubbles are formed (as shown in Figure 3(b)). With the filling of gas, the first complete independent bubble is formed (Figure 3(c)), and under the action of liquid phase pressure and friction, the speed decreases and rises (Figure 3(d)). When the bubble expands and rises, it drives the surrounding liquid phase to form a wake, which changes the pressure environment of the subsequent bubble and accelerates the generation of subsequent bubbles. In this process, due to the two-phase action such as wake, the force around the bubbles becomes more complicated. When two bubbles meet, the liquid film gradually becomes thinner and ruptures and merges (Figure 3(e)), or multiple bubbles accumulate (such as Figure 3(f)), there will be a single large bubble ruptured and decomposed by liquid squeezing (Figure 3(h)). Modeling analysis found that the bubble collapse point mainly appeared at the low end of the bubble. This is because during the formation of the bubble, a necked area is formed at the bottom of the bubble. The thickness of the liquid film at the integral connection part with the bubble is only half of the other areas. Under the complex two-phase force system, it is more prone to damage and break, causing the bubble to burst.
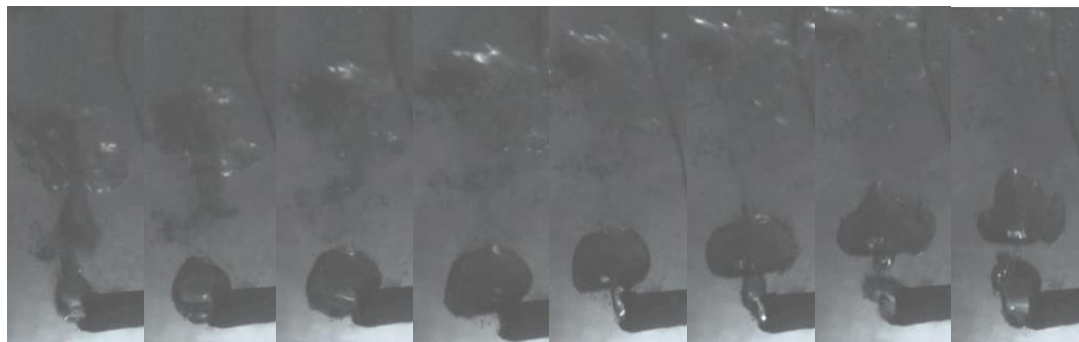

Figure 4. Water-based bubble formation process

To verify the model, a high-speed camera was used to observe the bubble formation process, and the result is shown in Figure 4. After the bubble comes out of the nozzle, it first forms a similar spherical bubble, and after the subsequent gas supplement, it expands and grows sharply. However, because the bottom is not separated from the nozzle, the shape is gradually mushroom-shaped due to the bridging force. As the bubble grows, the bottom bottleneck connection becomes thinner and breaks away, forming independent bubbles. The period of bubble formation to separation is about 100ms. As the gas is further filled, the charging speed is accelerated. Both the bubble formation speed and the initial kinetic energy at the time of separation are

greatly increased, which further drives the movement of the surrounding liquid phase and affects the shape and volume of the surrounding bubbles.

(1) Change rate of bubble volume

The experiment found that the expansion phase of the bubble lasts about 0.05s. Therefore, in the calculation, only calculate the state change of the bubble within the period of 0~0.05s, and the step size is 0.001s. Calculating bubble volume [8] and the relationship between volume acceleration and time are shown in Figures 5 and 6, A is the nozzle cross-sectional area. On the whole, the bubble has just formed in the early stage of formation, expands with a larger acceleration, and has a smaller volume, and then tends to grow linearly, and finally accelerates to separate from the nozzle.
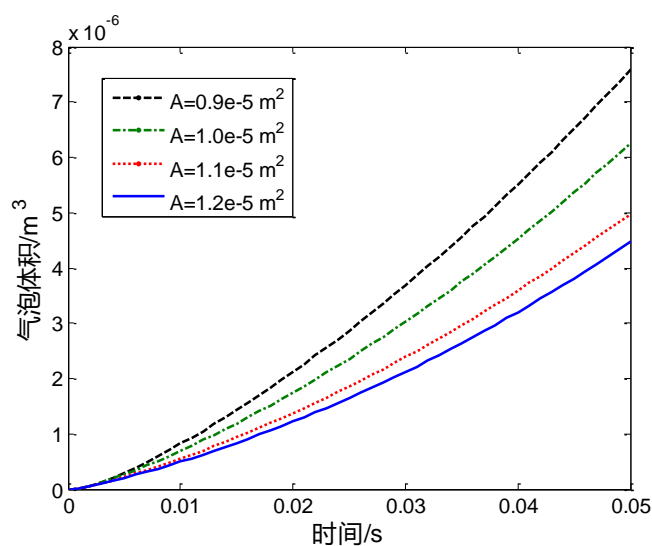

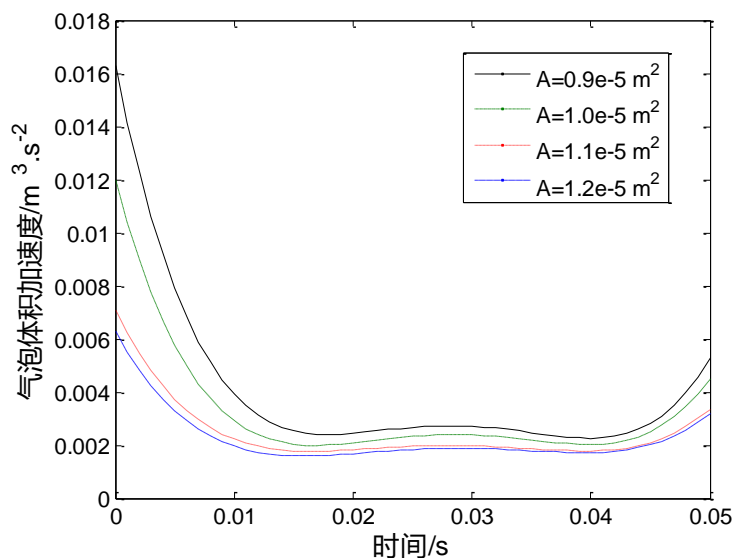Figure 5. The change of bubble volume with time at different A

Figure 6. Acceleration of bubble volume change at different A

To facilitate verification, compare the experimental results (A=0.00113 m2) with the calculated results, as shown in Figure 7. The limited volume of the tank and the surrounding liquid phase environmental conditions have little effect on it, and the bubbles are basically spherical. With the subsequent supplement

of gas, the volume of the bubble gradually increases. Under the combined influence of the surrounding environment and other forces, especially the disturbance of the liquid phase, the bubbles begin to deviate from the spherical shape and present an ellipsoidal or mushroom shape, which introduces certain errors in the calculation.
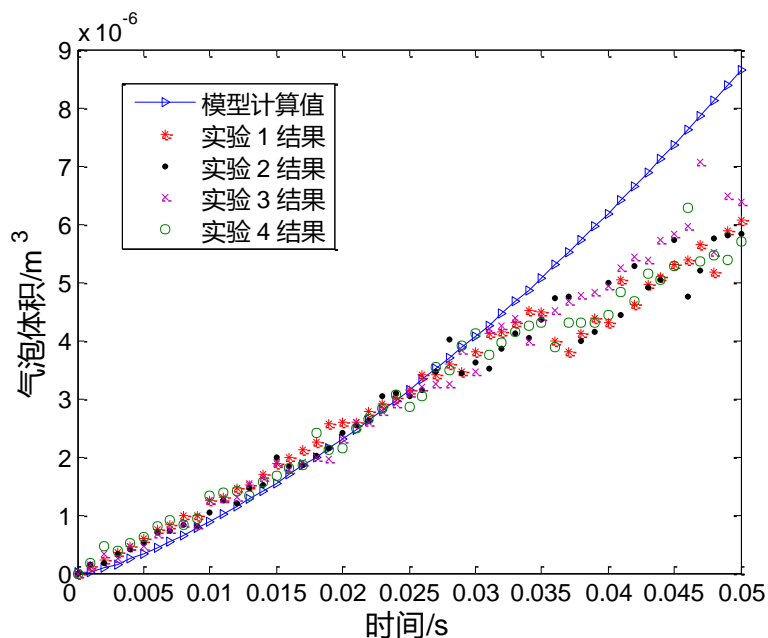

Figure 7. Comparison of calculation results and experimental results

(2) The influence of nozzle status and size on bubble size distribution

Table 1. Bubble size distribution formed by nozzles in different states

Radius (m)	Bubble Size Distribution(M)		
	Nozzle Up	Nozzle Horizontal	Nozzle Down
0.001	0.001~0.004	0.001~0.003	0.001~0.002
0.003	0.007~0.015	0.004~0.01	0.004~0.007
0.01	0.02~0.035	0.015~0.03	0.012~0.025

Because the bubble diameter distribution has a great influence on its extinction performance, experiments were carried out on different nozzle sizes and layout orientations. The results are shown in Table 1. The nozzle orientation has a greater influence on the bubble size, especially when the air velocity is increased. This is mainly caused by the shear action of the liquid relative to the bubbles. In addition, the smaller the nozzle diameter, the easier it is to form a dense group of fine bubbles, which helps to increase the effective bubble density, but it will delay the bubble formation speed. Experiments have found that 3 and 10mm nozzles can already form a bubble group with effective shielding thickness within 30s, and it takes twice as long to form a bubble group of the same size with a 1mm nozzle.

5. Conclusions

It can be seen from the comparison of the above calculation results and experiments that the theoretical

model established can basically be used to predict the bubble generation process, and its volume growth trend and change state can be in good agreement with the experiment, and can be further used to study the nozzle structure and state The effect on the formation of bubbles. Increasing the shear stroke of bubbles and liquid phase helps to form dense small-sized bubbles. Studies have shown that the size of the nozzle section has an important influence on the bubble formation volume and bubble formation speed.

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