



Acoustic cavitation structures produced by artificial implants of nuclei



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ABSTRACT

High-density controllable bubble structures are produced in the vicinity of radiating surface by artificially implant nuclei. Two kinds of typical cavitation structures produced by artificially implant nuclei are investigated. The focusing action and the physical origin of jet-induced cone-like bubble structure are analyzed. The sonochemical activity of cavitation structures is measured by using the standard method of potassium iodide dosimetry. The controllability of cavitation bubble cluster in the acoustic field is also discussed in this work.

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1. Introduction

Ultrasonic cavitation field in liquid provides a unique environment for chemical reactions and has many applications [1]. Each bubble in the cavitation field acts as a single sonochemical reactor in itself. However, cavitation bubble distribution is spatially inhomogeneous; they can form different structures in the ultrasound field [2–5]. In order to increase the efficiency of sonochemical reactors, it is necessary to study cavitation bubble structure: 1. increase the spatial density of bubbles; 2. control the position and structure of bubble cloud. In this work we present a method to produce high-density controllable bubble structures in the vicinity of radiating surface by artificially implant nuclei. These high-density cavitation structures can be produced at relatively low acoustic radiation intensity, which will improve the performance of sonochemical reactors. We also found that this kind of cavitation can be well controlled, and we even can form letters with these cavitation bubbles. The controllability of cavitation bubble cluster may be used in the other industrial units.

2. Experiment

The experimental setup (as shown in Fig. 1) consist of the ultrasonic cavitation devices, the imaging and illumination system, gap adjuster, submerged jet device, hydrophone and oscilloscope, etc. The high power ultrasound is produced by S6 ultrasonic processor (Jiuzhou Ultrasonic Technology Co., Ltd. China) with a frequency of

18.5 kHz and a maximum input electric power of 100 W. The ultrasonic horn has a plane radiating surface ($d = 50$ mm) and oscillated as a piston with simple harmonic motion. The ultrasonic horn is submerged in water in a transparent chamber (600 mm $\times$ 330 mm $\times$ 330 mm). Cavitation structure is recorded with three high-speed camera (Phantom v710, Vision Research Inc., USA), Photron Fastcam-Super 10 K (Photron Ltd., Japan) and Photron Fastcam SA-1. The positions of light source and high-speed camera (shooting angle) are adjusted for a better photographic effect. T6 ultraviolet spectrophotometer (Purkinje General Instrument Ltd., China) is used in the experiment.

3. Results and discussion

3.1. Tailing zone

Most violent cavitation bubbles originate from the vibrating surface, and from there, these bubbles fast drift to the near liquid region [4]. It is found that when the acoustic intensity $I = 3\text{--}5$ W/cm², there are no strong cavitation structures (for example Smoker or CBS (cone-like bubble structure)) in the vicinity of radiating surface, but if we put a small objects which can trap small air bubbles (for example syringe needle or capillary tube) in this area, a tail of cavitation bubbles will be produced (as shown in Fig. 4). We call this area “tailing zone”. The range, tail length and tail direction are measured for a syringe needle ($d = 0.7$ mm), as shown in Fig. 2. The curved lines with arrows represent the direction of bubble motion in the tail. The three yellow line represent the contour line of tail length ($L = 0$ mm; $L = 15$ mm; $L = 25$ mm). The lower part of Fig. 2 shows a composite image of superimposing 35

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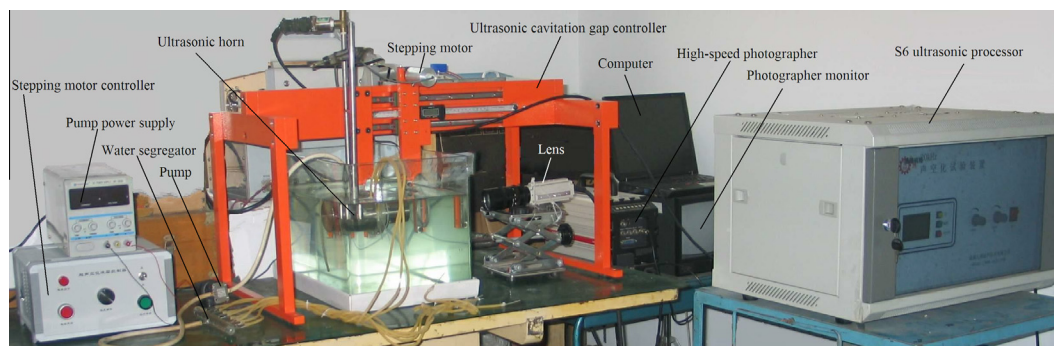


Fig. 1. Experimental set up.

high-speed photos of bubble tails at the typical position. It can be seen from Fig. 2 that the magnitude and the direction of acoustic radiation forces on bubbles variation with position in the nose-cone-shaped tailing zone. So the force that cavitation bubbles clung to the end of a curved capillary tube ($d = 0.3$ mm) exert on the capillary F are measured in Fig. 3 (the radiation force on the capillary tube has been eliminated). Five positions along the axial line are chosen to measure the force (Sampling frequency 250 S/s. The error of these measurements is estimated to be approximately ± 0.07 mN.). The radiation force on bubbles can be reflected indirectly through F . It can be seen that F decreases gradually with increasing distance L . The radiation force puffs away the bubble cluster from the capillary tube end again and again, which cause the temporal fluctuation of F . When the capillary tube is very close or very far from radiating surface, the behavior of cavitation bubbles clung to the capillary tube end is stable, so the force fluctuates gently.

3.2. Two kinds of typical cavitation structures produced by artificial implant nuclei

3.2.1. Tailing bubble structure (TBS)

Pits structure tends to collect and hold wandering cavitation bubbles in ultrasonic field [6]. So the ends of syringe needle or capillary tube which trap small air bubbles will become a source of nu-

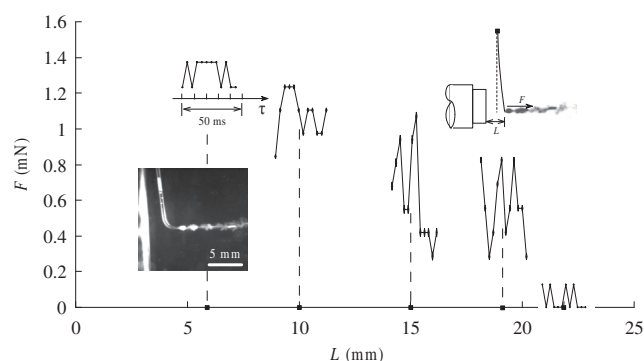


Fig. 3. The forces exerted on a capillary tube in the tailing zone.

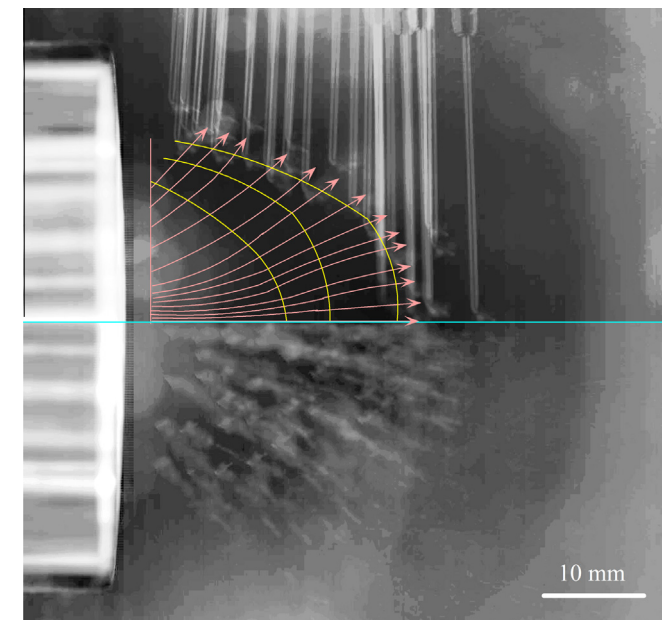


Fig. 2. The tailing zone in the vicinity of radiating surface.

clei in the tailing zone. These cavitation bubbles move away from radiating surface due to acoustic radiation forces. These continuous generated bubbles form a tail of cloud. We call them tailing bubble structure (TBS), as shown in Fig. 4. The cavitation bubbles usually separate into several bubble cluster which move in the intermittent TBS. The TBS is formed by a few large bubbles ($d_{\max} = 0.4$ – 1.2 mm, the bubble diameter at the rarefaction phase of ultrasound) and numerous small bubbles ($d_{\max} \leq 0.1$ mm), as shown in Figs. 5, 6 and 8. The small bubbles collapse completely and they are too small for optical resolution in its minimum volume. The large bubbles collapse incompletely, so it easy to track their motion. Fig. 5 shows the growth and collapse of cavitation bubbles in two acoustic cycle with a curved syringe needle ($d = 0.7$ mm) as a nuclei source. It can be seen from Fig. 5 that the small bubbles collapse, rebound or merge almost at the same place without much translational motion in several acoustic cycles, so the shape of bubble cluster remain stable when it move away from radiating surface. The large bubbles are generated not from the shedding of air bubble which attached to the pit structure of needle, but from the collection of bubble cluster (as shown in Fig. 6).

3.2.2. Jet-induced bubble structure (JBS)

We can implant nuclei to tailing zone artificially by a submerged jet of water, and cavitation bubble structure can be formed in this way (as shown in Fig. 7). We call the bubble structure which induced by a submerged jet of water in the tailing zone jet-induced bubble structure (JBS). JBS and TBS are similar, they are formed by large bubbles and small bubbles, and the life cycle of small bubbles is shorter than that of large bubbles (as shown in Fig. 8). So the interaction of cavitation bubbles and air bubbles may be happened from microscopic perspective [7,8]. JBS differs from TBS in that the spatial density of bubbles is higher and the direction of bubble motion can be controlled.

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