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Generation and control of acoustic cavitation structure

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ABSTRACT

The generation and control of acoustic cavitation structure are a prerequisite for application of cavitation in the field of ultrasonic sonochemistry and ultrasonic cleaning. The generation and control of several typical acoustic cavitation structures (conical bubble structure, smoker, acoustic Lichtenberg figure, tailing bubble structure, jet-induced bubble structures) in a 20–50 kHz ultrasonic field are investigated. Cavitation bubbles tend to move along the direction of pressure drop in the region in front of radiating surface, which are the premise and the foundation of some strong acoustic cavitation structure formation. The nuclei source of above-mentioned acoustic cavitation structures is analyzed. The relationship and mutual transformation of these acoustic cavitation structures are discussed.

1. Introduction

Sonochemistry has been the subject of laboratory study for several decades, but success in scaling sonochemical reactions has been very limited [1]. Some problems should be solved before significant commercial activities can occur. For example, the cavitation areas are small and very difficult to control, sonotrode or transducer erosion causes contamination of the liquid to be treated, and energy conversion efficiency and economical efficiency are poor. In order to solve the above problems, the investigation on the generation and control of acoustic cavitation bubble cloud is needed. It is generally known that cavitation bubble distribution is spatially inhomogeneous; they can form different structures in the ultrasound field [2–6]. Robert Mettin [2] (2005) provided a classification based on visual aspects of acoustic cavitation, and gave a brief introduction to these acoustic cavitation structures (streamers, filaments, bows, rings, jellyfish, starfish, conical bubble structure, flare structure, smokers and webs). The classification is very useful although it is still not widely used. Iskander S. Akhatov [7] (1996), Ulrich Parlitz [8] (1999) and Robert Mettin [9] (1999) investigated the dynamics of acoustic Lichtenberg figure in acoustic cavitation fields by experimental and numerical simulation. Alexei Moussatov [3,12] (2003), Bertrand Dubus [10] (2010) and Olivier Louisnard [11] (2012) investigated conical bubble structures in the vicinity of the radiating surface of an ultrasonic transducer, and proposed some explanations for the physical origin of the structures. Lixin Bai [5] (2012) investigated experimentally the structures and evolution of smoker in a 20 kHz ultrasonic field. Lixin Bai [6] (2014) investigated two kinds of typical cavitation structures (tailing bubble structure and jet-induced bubble structure) produced by artificially implant nuclei. This paper conducts an experimental investigation on five typical acoustic cavitation structures (acoustic Lichtenberg figure, conical bubble structure, smoker, tailing bubble structure and jet-induced bubble structure), and discusses the nuclei source, the relationship and mutual transformation of these structures for a better understanding of cavitation field in sonochemical reactors.

2. Experiment

The experimental setup consists of the following major components: the ultrasonic cavitation devices, the high-speed imaging and illumination system, step motor-driven gap adjusting system, submerged jet device, hydrophone and oscilloscope (as shown in Fig. 1).

The ultrasonic horn was submerged in water in a transparent chamber (600 mm × 330 mm × 330 mm). Fresh tap water (with many nuclei) is used in the experiment so as to reduce the cavitation threshold. The similar results can be obtained in deionized water but with less cavitation bubbles, as compared to in tap water. The water temperature in the experiments is about 20 °C.

Several different ultrasonic cavitation devices are used in the experiment so as to produce different kinds of acoustic cavitation structure (as shown in Fig. 2).

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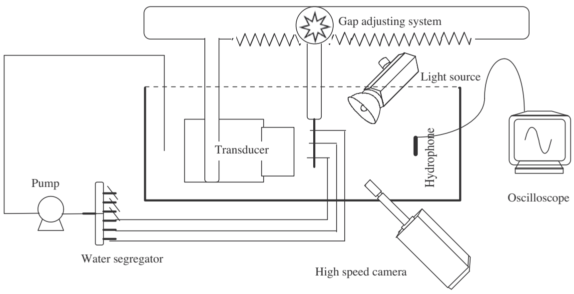


Fig. 1. Experimental setup.

Acoustic 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, and is illuminated with HALOGEN lamp (2600 W) and PI-LUMINOR high-light LED lamp (150 W). The positions of light source and high-speed camera (shooting angle) were adjusted for a better photographic effect.

Step motor-driven gap adjusting system is used to fix the transducer and adjust the distance between the radiating surface and metal net (or syringe needle, or nozzle) in the experiment. Submerged jet device is used to produce a stream of flow in the still body of water in chamber. The jet velocity can be adjusted by changing the driving voltage of pump.

3. Results and discussion

3.1. Conical bubble structure

Conical bubble structures (CBS) [3,6,12] are common in cavitation field produced by sonotrodes (as shown in Fig. 3). The radiating surface is covered by bubbly web structures (as shown in Fig. 9)

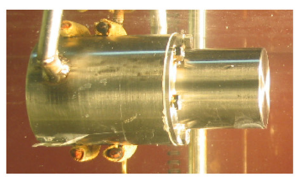
Serial number	Transducer	Proformance
1		Manufacturer: Jiuzhou Ultrasonic Technology Co., Ltd. China Frequency: 18.5 kHz Radiating surface diameter: 50 mm Piezoelectric plate diameter = Radiating surface diameter
2		Manufacturer: Institute of Acoustics, Chinese Academy of Sciences Frequency: 20 kHz Radiating surface diameter: 80 mm Piezoelectric plate diameter < Radiating surface diameter
3		Manufacturer: Jiuzhou Ultrasonic Technology Co., Ltd. China Frequency: 40 kHz Radiating surface diameter: 30 mm Piezoelectric plate diameter = Radiating surface diameter
4		Manufacturer: Institute of Acoustics, Chinese Academy of Sciences Frequency: 20 kHz Radiating surface diameter: 20 mm Piezoelectric plate diameter > Radiating surface diameter

Fig. 2. The transducers used in the experiments.