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Surface tension and quasi-emulsion of cavitation bubble cloud

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ABSTRACT

A quasi-emulsion phenomenon of cavitation structure in a thin liquid layer (the thin liquid layer is trapped between a radiating surface and a hard reflector) is investigated experimentally with high-speed photography. The transformation from cloud-in-water (c/w) emulsion to water-in-cloud (w/c) emulsion is related to the increase of cavitation bubble cloud. The acoustic field in the thin liquid layer is analyzed. It is found that the liquid region has higher acoustic pressure than the cloud region. The bubbles are pushed from liquid region to cloud region by the primary Bjerknes forces. The rate of change of CSF increased with the increase of CSF. The cavitation bubbles on the surface of cavitation cloud are attracted by the cavitation bubbles inside the cloud due to secondary Bjerknes forces. The existence of surface tension on the interface of liquid region and cloud region is proved. The formation mechanism of disc-shaped liquid region and cloud region are analysed by surface tension and incompressibility of cavitation bubble cloud.

1. Introduction

Cavitaion refers to the formation and subsequent dynamic life of bubbles in liquids subjected to a sufficiently low pressure [1]. The high-energy concentration and the mechanical, optical, acoustical, and chemical effects of cavitation attracted the multitudinous scientist's attention and the research interest [2]. Applications of cavitation span many industrial sectors, from peening treatment, through ultrasonic lithotripsy, sonochemistry, ultrasonic cleaning and wastewater treatment, to jet cutting. Each bubble in the cavitation field acts as a single localized "hot spot" or a sonochemical reactor. The visual observations [3] indicate that cavitation bubbles rarely exist in isolation and are present in the form of clusters or clouds. Thus, the bubble dynamics should also be influenced by the growth and collapse of the surrounding bubbles. Hence it is more realistic to consider a cluster or cloud rather than a single bubble for the investigation of cavitation phenomenon. It is generally known that cavitation bubble distribution is spatially inhomogeneous; they can form different structures in the ultrasound field [4,5]. Iskander S. Akhatov [6] (1996), Ulrich Parlitz [7] (1999) and Robert Mettin [8] (1999) investigated the dynamics of acoustic Lichtenberg figure in acoustic cavitation fields. Alexei Moussatov [5] (2003), Bertrand Dubus [9] (2010) and Olivier Louisnard [10] (2012) investigated conical bubble structures in the vicinity of the radiating surface of an ultrasonic transducer. Lixin Bai [11,12] (2012, 2014) investigated experimentally smoker cavitation structure and the cavitation structures produced by artificially implanting nuclei.

The conditions and characteristics of different types of cavitation structures are different. The cavitation in thin liquid layer was first investigated by Alexei Moussatov [13] (2005). He found that this configuration lead to a large amplification of the acoustic pressure which makes the generation of cavitation possible at low power or in a wide frequency range. García-Atance Fatjó [14] (2010) investigated the cavitation ring in a thin liquid layer using a theoretical model based on the combination of Fluid Mechanics and Analytical Mechanics. Lixin Bai [15] (2016) investigated the memory effect and redistribution of cavitation nuclei in a thin liquid layer.

The cavitation structures in a thin liquid layer show some new characteristics because of the two-dimensional nature of thin liquid layer. In this paper, a quasi-emulsion phenomenon of cavitation bubble cloud in a thin liquid layer is investigated. The present work is, from the authors' knowledge, the first analysis of surface tension of cavitation bubble cloud.

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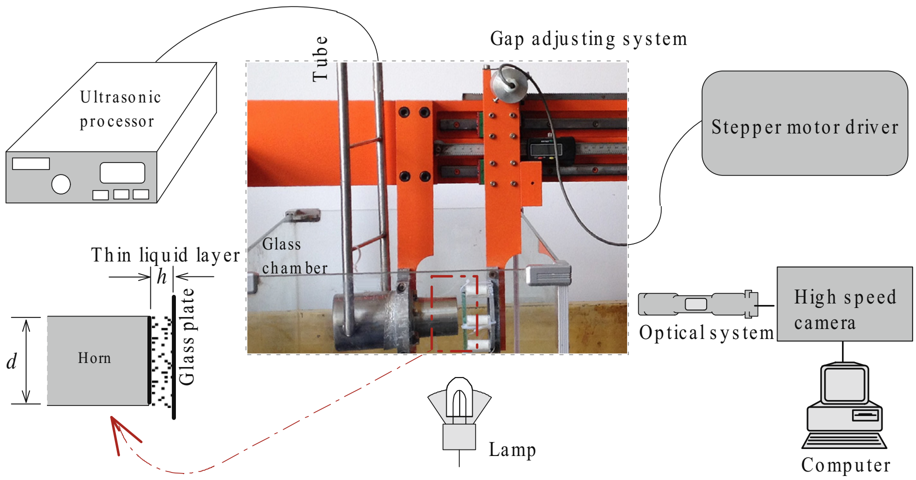

Fig. 1. Experimental set-up to visualize the cavitation structures in a thin liquid layer of varying thickness. The subfigure in the lower left corner is a schematic diagram of thin liquid layer.

2. Experiment

Fig. 1 illustrates the experimental setup when the cavitation structure in the thin liquid layer is recorded. The experimental setup consisted of the ultrasonic cavitation devices, the high-speed imaging and illumination system, step motor-driven gap adjusting system, etc. The piezoceramic sandwich transducer is well enveloped and can be submerged in water completely. The ultrasonic horn is mounted horizontally 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 high power ultrasound is produced by three ultrasonic processors (Jiuzhou Ultrasonic Technology Co., Ltd. China) with a frequency of 20 kHz (radiating surface diameter, d = 50 mm), 30 kHz (d = 38 mm) and 40 kHz (d = 30 mm) and a maximum input electric power of 100 W. The radiating surface diameter of the sandwich piezoelectric ceramic ultrasonic transducer equals to the diameter of piezoelectric plate. Step motor-driven gap adjusting system (minimum adjustment distance: 20 μm) is used to fix the transducer and adjust the distance (liquid layer thickness, h) between the radiating surface and transparent reflection plane (glass plate thickness: 5 mm) in the experiment. Cavitation structure is recorded with a high-speed camera (Photron Fastcam SA-1, Photron Ltd., Japan) equipped with two long distance microscopes (Zoom 6000, Navitar, USA; LM50JCM, Kowa, Japan) respectively. The pictures are taken in a framing rate of 500 fps (1024 × 1024 pixels and 20 μm pixel size) to 100,000 fps (320 × 128 pixels) for the whole or the part of cavitation structures. The frames are illuminated with HALOGEN lamp (2600 W) and PI-LUMINOR high-light LED lamp (150 W). The positions of

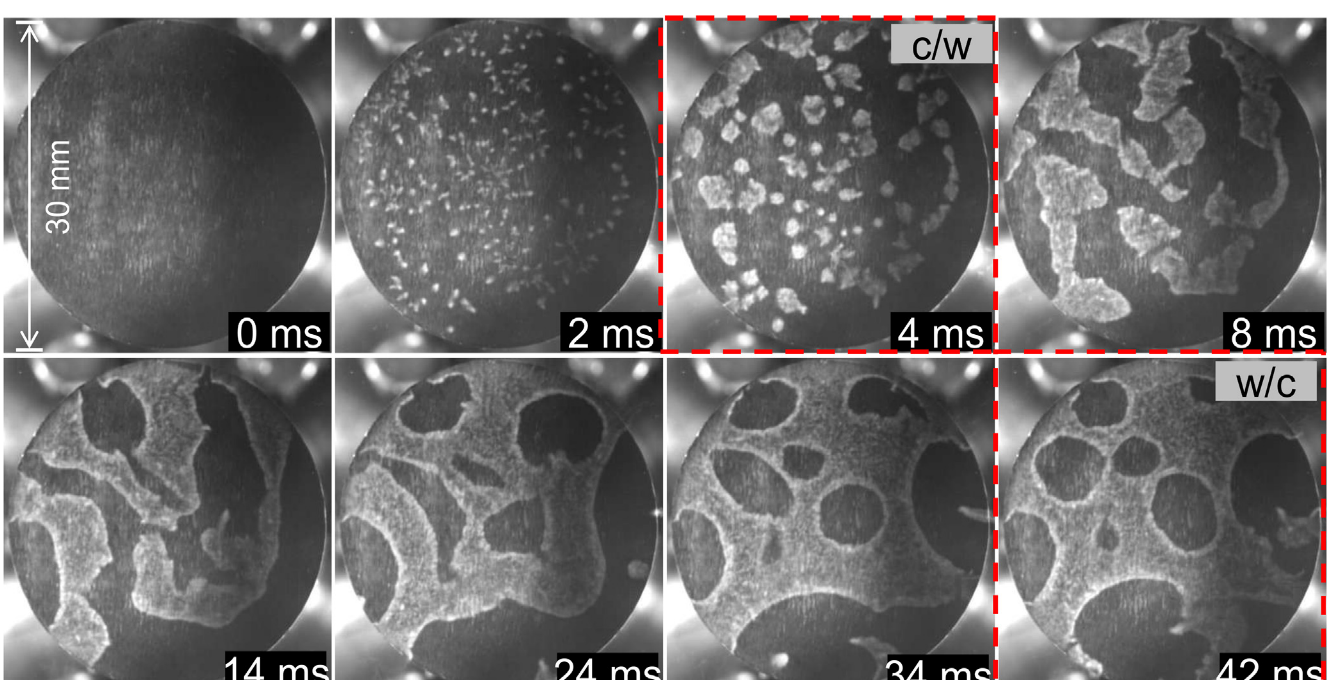

Fig. 2. The inception of cavitation structures (f = 40 kHz, h = 1.01 mm).