Bimodal Bubble Cluster as a Result of Bubble Fragmentation in a Bipolar Acoustic Pulse

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Abstract. The bubble dynamics is theoretically and experimentally investigated in a bipolar acoustic pulse. Irregular bubble oscillations result in small fragments chipping off from initially large bubbles and hence formations of a bimodal bubble cluster. Near to a neck between bubble and its fragment a local spot with high pressure and temperature appears that can result in light emission.

INTRODUCTION

The problem of propagation of an acoustic pulse in liquids with pre-existing gas and cavitation bubbles is of a great interest in many applications [1, 2]. In the compression phase the bubbles shrink and, hence, gain an additional potential energy, which is liberated in the phase of rarefaction. For this reason a two-phase flow becomes essentially non-equilibrium. It results in complicated flow processes accompanied by bubble collapse, fragmentation, coalescence as well as formation of significant non-uniformity of thermodynamic parameters of the flow. These processes are an object of proposed theoretical and experimental study.

EXPERIMENTS

A collapse of bubbles in an external pulse was modeled experimentally, when the collapse of a group of weakly-interacted bubbles was investigated during acoustic cavitation in water. In the experiments a compression of cavitation bubbles in a pulse acoustic wave is conducted in a set-up shown in Fig. 1. An electromagnetic generator (1) based on the principle from [3] and a spherical reflector (3) are used. The flat

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transducer (2) with an aperture of D = 90 mm is installed in a cubic cuvette with glass windows. Pressure measurements were done with a fiber optic hydrophone (6) (FOPH 300, 140 um diameter, 50 MHz electronic bandwidth [4]) oriented parallel to the axis of a transducer. To observe bubble dynamics a high-speed camera (4) (IMACON 468, DRS Hadland, 10 ns exposure time, 8 frames) with a xenon flash lamp (5) is used. The signal is recorded using a oscilloscope (7) (TDS 784A, Tektronix, 1 GHz).

In Fig. 2 a bubble dynamics near to the focus of a transducer are shown. After a compression pulse (A) and a rarefaction pulse of about -2 MPa (B) pass from a flat transducer (is located on the right) through an area of observation a bubble radius increases and a cavitational cluster is formed. After reflection from a spherical reflector the pressure in a reflected pulse has a maximum of about 22 MPa in the point F on a distance of R/2 from the reflector (R is radius of the reflector). After a compression pulse (C) passes through the cavitational cluster a collapse of bubbles in the pulse (SW in Fig. 2) and subsequent expansion and distortion of the form of the bubble after a rarefaction pulse (D) were observed (Fig. 2). The distortion of the form of bubbles as a cone is an evidence of a non-spherical collapse, which is accompanied with a cumulative phenomenon [1]. The speed of the cumulative jets is directed to the focus if a bubble was before the focus on a course of compression pulse, and is directed from the focus in another bubble location.

For the largest bubbles the distortion is enough to notice come off of a fine bubble (1) from a top of a cone (Fig. 2), as well as was shown earlier in [2]. Thus, with shock wave influence on liquid with bubbles there is their distortion and fragmentation. The size of fragments is less in tens time than the size of initial bubbles. Hence, the generated cluster has a bimodal distribution of bubble's size.

THEORY

Under numerical simulations it was assumed that pulse of compression represents sinusoidal wave having duration of 3,3 ms and amplitude of 11,5 MPa, the pulse of rarefaction is a wave with the same duration and amplitude of - 11,5 MPa. The studied region is a channel having diameter of 4 mm and length of 35 mm, filled with water under the initial pressure of 0,1 MPa. In the center of the channel a spherical micro bubble is placed with initial diameter of 20 um. Modeling of bubble dynamics at the passing of initial pulse through the flow was performed within the framework of hydrodynamic approach on the base of laws of conservation of mass, momentum and energy for two-dimensional non-stationary motion of ideal compressed medium for the event of axial symmetry [5]. Borders between fluid and gaseous fragments were considered to be contact discontinuity surfaces. The flow fields of thermodynamic parameters were computed inside each fragment.

In the phase of rarefaction of the initial pulse, a micro bubble begins to enlarge, its longitude diameter reaches values of 566 um, and transverse one is of 339 um by instant t = 16,8 us, measured from the beginning of wave moving through the bubble. Herewith behind the bubble on its surfaces, a "nose" is formed, that is a gaseous jet of

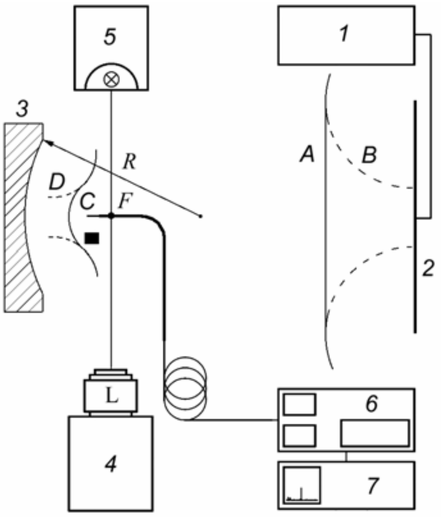

FIGURE 1. Scheme of experiment. The black rectangle - field of cinematographing.

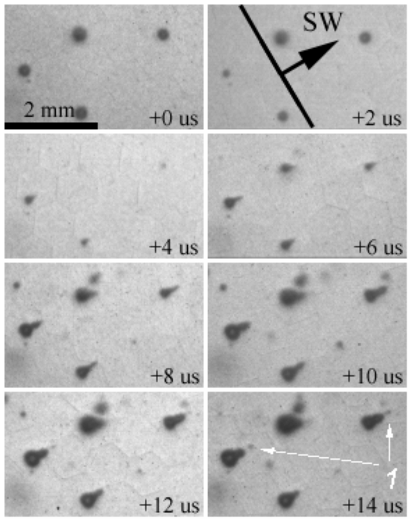

FIGURE 2. Cavitational bubble dynamics in an external acoustic pulse wave. 1 - fragment of bubble.

187 um long, having the same direction as the initial pulse. Note that similar effect is observed in described above experiment.

Process of micro bubble expansion is accompanied by formation of a secondary compression wave, which reflected from the walls of the channel causes a collapse of the "nose" by instant t = 18,2 us. Herewith at the moment of the collapse, a pressure value at the spot beside bubble surface grows up to 0,8 GPa, and gas temperature here is up to 11000 K. This effect should be accompanied by the light radiation of gas in the local area with such values of thermodynamic parameters, that allows us to suggest an explanation of the nature of local sonoluminescence (formation of shining spots at a bubble surface) observed in the experiments [1]. Similar "nose" is formed on the opposite side of the bubble by t = 22,6 us, whose collapse takes place at t = 24,0 us.

Let consider a propagation of the initiating pulse through the medium with sufficiently large initial bubble, having initial diameter of 1mm. As can be seen from the Fig. 3, by instant t = 4,8 us the volume of the bubble decreases to 0,51 of the initial value (due to the wave of compression). Here lighter tones on the figure correspond to compression waves, and more dark tones correspond to rarefaction waves. In this case the "nose" is also formed on the bubble surface by instant t = 15,6 us, and its collapse occurs by t = 17,4 us. The process of the collapse is accompanied here by the fragmentation of the "nose" (t = 16,8 us). The generated fragment begins to oscillate in the acoustic field of the big bubble, reaching the most size of the mean diameter of 135 mm at t = 19,6 us and collapsing at t = 18,0 us and t = 25,6 us. In the process of fluctuations a distance between the bubbles increases. Thereby the collapse of "noses" of the bubbles having sufficiently great diameter can be accompanied by forming of a second bubble fraction with considerably smaller diameter that brings about formation of bimodal bubble cluster.

If the initial pulse gets through the medium with several micro bubbles, a flow field becomes greatly complicated with formation of multiple "noses" and their following fragmentation. Herewith bubbles with toroidal structure can be observed in computations as well as effects of bubble coalescence. However distribution of bubble sizes also has a bimodal type mentioned above.

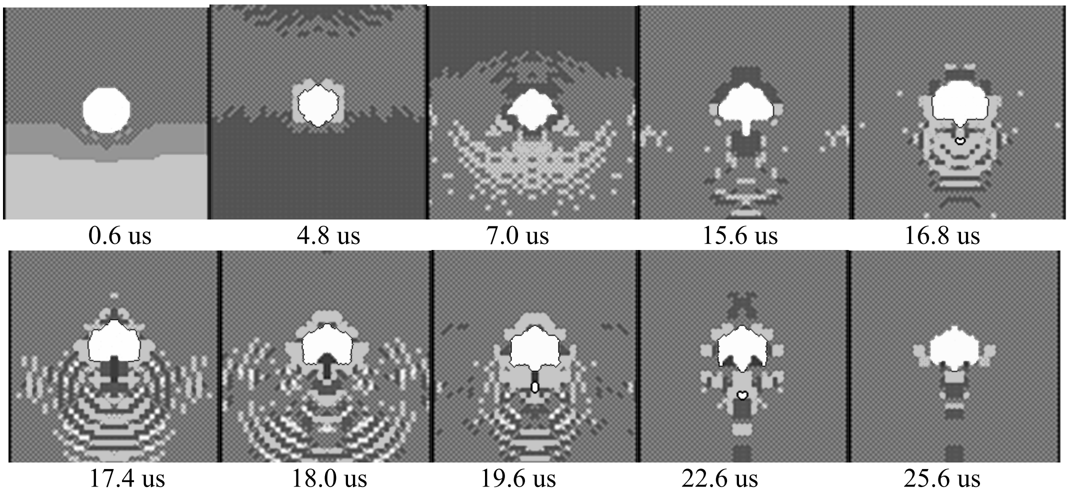

FIGURE 3. Bubble fragmentation behind acoustic wave.

CONCLUSIONS

In the paper it was found theoretically and experimentally that behind a bipolar acoustic wave a bimodal bubble cluster is formed due to fragmentation of initially large bubbles. Process of fragmentation is accompanied by generation of localized spots within a bubble with high values of thermodynamic parameters that should result in phenomenon of light emission in the local area.

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