Dynamics of a Bimodal Bubble Cavitation Cluster in a Bipolar Acoustic Pulse

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Abstract. Dynamics of cavitation cluster in a focusing shock wave far from boundaries is investigated. An electromagnetic generator of a convergent acoustic pulse with a strong rarefaction component from a transducer as a spherical segment was used. Two fractions of bubbles (growing and collapsing in an internal positive pressure) were revealed on the early stage of formation of the cluster.

INTRODUCTION

Dynamics of bubble cluster plays a central role in research of sonoluminescence and sonochemistry [1]. According to existing assumptions the strengthening (increase of temperature and pressure inside a bubble) of a collapse can occur in a polydisperse cluster [2]. In this paper some results on bubble interaction in a focusing acoustic pulse are submitted.

EXPERIMENT

The scheme of experiment is shown in Fig. 1. The cavitation is generated in focusing acoustic pulse from an electromagnetic generator (1) (2 us discharge period) in a polyamide cuvette (2) with glass windows filled with distilled, demineralized and saturated with air water at room temperature. The pressure in the focus of a negative pulse is varied from -18 to -42 MPa [3]. The cavitation cluster is backlit with a xenon flash (3), and its dynamics is recorded using a high-speed ICCD camera (5) (Imacon 468, DRS Hadland, 10 ns exposure time, 8 frames). A sufficient magnification of up to 3 um per pixel is achieved with an optical objective (Nikon) or a long-distance

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microscope (4) (Questar QM-100). The depth of the focus of the microscope was about 4 mm. An ellipsoidal cavitation cloud (3, Fig. 2) is formed in the focus of the transducer.

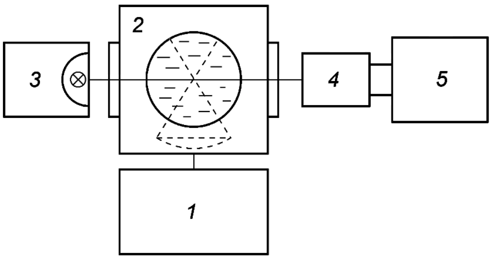

FIGURE 1. Scheme of experiment.

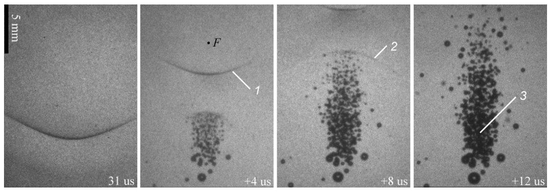

FIGURE 2. Cavitation in focusing shock wave.

THEORY

The modeling is performed for a hydrodynamic flow in the rigid tube of 0.4 mm in diameter filled with water under the initial pressure p_0 = 0.1 MPa. Gas bubbles were placed at the tube center with a pressure inside equal to p_0. In the beginning a velocity of the medium was equal to zero. Initiating pulse run from the bottom to the top and had a profile of a flat half-sinusoidal rarefaction wave. The length of phase was 0.5 mm, the wave amplitude was 11.5 MPa.

A two-phase compressible flow of a liquid with gas bubbles was described by non-stationary two-dimensional Eulerian equations of conservation of mass, pulse and energy. Diffusion effects were not considered. The thermodynamic flow field was computed both in the liquid and within the bubble. Hence, the solution can be scaled to the best fit the experiment. This technique is described in more details in [4].

RESULTS

In Fig. 3 three series (a, b, and c) of microscopic images (image width of 1 mm, time interval of 0.2 us between images) of development of cavitation processes at the center of the cluster (3, Fig. 2) are shown. The peak negative pressure in the focus was -39 MPa. Smaller bubbles (5) collapse in a pressure field of a wave of compression following behind the point (3), which correspond to a secondary compression wave because of cavitation (SCW) [5]. It can be seen that the collapsing bubble is a source of a shock wave (7).

In Fig. 4 a dependence of a bubble radius on time measured from photo-recording are shown. The time interval $\Delta t = t - t_A$ for each bubble was measured from the moment of arrival of a shock front (2, Fig. 3) to a point with coordinates of center of a bubble $t_A = (F+z)/c_0$ (c_0 is a sound speed in water). It is revealed from the kinematics of bubble behavior that in a time interval Δt from about 3.0 to 4.0 us two fractions of bubbles (I - growing bubbles, II - collapsing bubbles) are formed.

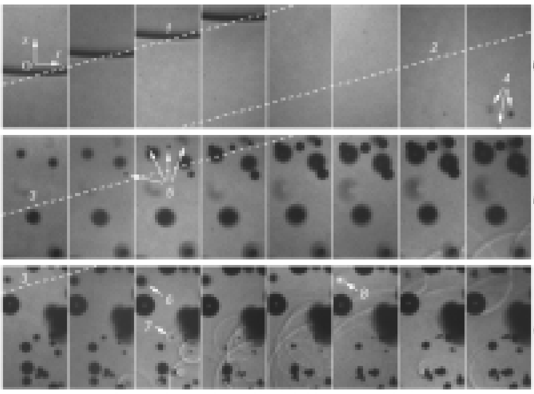

FIGURE 3. Micro-photo recording of cluster.

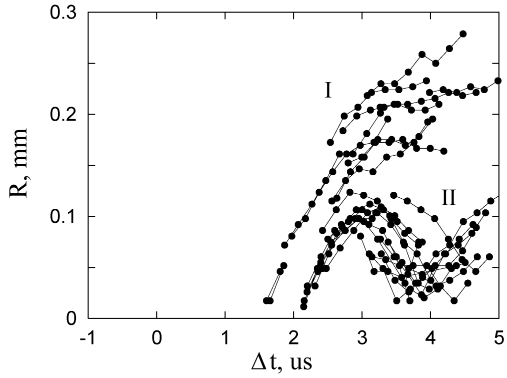

FIGURE 4. Kinematics of bubble radius.

It is revealed that the bubbles become visible in a rarefaction wave (2-3) in the first fraction after about Δt = 1.6 us (4, Fig. 3), and bubbles of the second fraction become visible about Δt = 2.1 us (5, Fig. 3) after the moment of arrival of front of a compression wave. The distribution of smaller bubbles in a cluster in the focal plane has a maximum on the z-axis with dispersion of 1.2 mm. The distribution of larger bubbles is about homogeneous in the field of observation equal to 2x3 mm. The average concentration of lager bubbles does not exceed $n_I = 3.3\ 10^2$ cm^{-3} and smaller bubbles $n_{II} = 6.8\ 10^3$ cm^{-3}.

The bubbles interact both by SCW, and by waves from bubble collapse (7, Fig. 3). In our experiments the amplitude of the latter remained below the noise level of FOPH (approximately 1 MPa). In other words, the presence of the fraction of smaller bubbles slightly influences on the dynamics of larger bubbles.

The pressure in SCW can be estimated from dynamics of a bubble using the inverted Rayleigh's formula $p_{eff} = 0.837\ (R_{max}/T_c)^2\ \rho$, where R_{max} is a maximum radius of a bubble, T_c is a collapse time, ρ is a density of a liquid. In the photo-recording a collapse of the bubble (8, Fig. 3) with maximum radius of 90 um (6, Fig. 3) occurs in approximately 0.6 us. We have found p_{eff} = 20 MPa for a positive pulsation of pressure in SCW following behind a wave of rarefaction, which is in a good agreement with the peak value measured by a hydrophone in [3].

As is known, with an influence of an external flat shock wave there is a distortion of the spherical form of a bubble [6]. In our case after the first rebound the spherical form of a bubble is preserved. Hence the first collapse occurs more spherically than in a flat wave. Further (Δt > 5 us) bubbles in both fractions extend and coalescence.

In Fig. 5 the result of modeling of two bubble with different initial radius of 2 um and 35 um is presented (distance between bubbles is 335 um). Dark tones in the Fig.4 correspond to waves of compression, light ones – to waves of rarefaction. The bubbles start to grow in a rarefaction wave. Expanding bubbles generate the secondary compression waves, which deform the bubbles. A collapse of the smaller bubble occurs, and at t = 0.9 us it becomes invisible in the figure. Though in some moments of the time (t = 0.6-0.7 us) sizes of the bubbles are close to each other, the process is different from a case with a single bubble. As a result, a period of the first pulsation of the micro-bubble is vastly reduced. For instance, the pressure p_{eff} was 4.7 MPa.

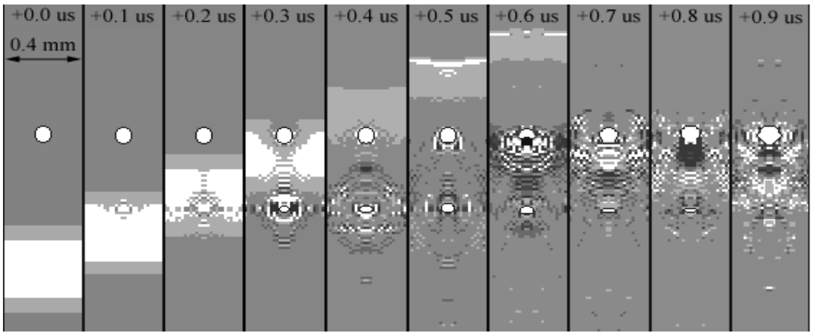

FIGURE 5. Modeling bubble dynamics in a rarefaction wave.

CONCLUSION

On the early stage of cluster formation two fractions of bubbles are revealed. Depending on initial radius of its nuclei a bubble starts to grow or to collapse from the certain moment of time in transformation of a rarefaction wave into the compression one. The pulse compression in an internal positive pressure of about 10 MPa is curried with preservation of a spherical form of a bubble.

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