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DYNAMICS OF BUBBLE SUPERCOMPRESSION IN ORGANIC LIQUIDS

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Summary Theoretical research of vapor bubbles in deuterated acetone and benzol is conducted. On the basis of the developed models of a single bubble and bubble cluster the dynamics of bubbles formed during maximum rarefaction in the liquid is investigated. It is shown that during the rapid contraction of a bubble a shock wave is formed inside it. Shock wave focusing in its center leads to violent rise in density (10^4 kg/m^3), pressure (10^{10}–10^{11} bar) and temperature (10^8–10^9 K), high enough to produce nuclear reactions. The diameter of the neutron emission zone is about 100 nm. It has been found out that the intensity of the bubble collapse and the number of emitted neutrons increase if one varies the phase of nucleation, the positive pressure wave amplitude, the liquid temperature, and when one switches on the mechanism of bubbles coagulation in the cluster during its simultaneous explosion.

INTRODUCTION

According to experimental data [1] neutron emission and tritium production can be observed during acoustic cavitation in D-acetone, that means the achievement of supercompressed state of matter inside bubbles at collapse. For theoretical confirmation and explanation of the phenomenon systematic research on the compression of vapor bubbles oscillating in a cluster, by the force of large amplitude standing acoustic wave, is carried out.

Two model problems are considered. The first deals with the research on the dynamics of a single bubble enforced by the given pressure field to model pressure in the bubble cluster. Parametric investigations are carried out in such a setting to obtain main features of the process of bubble collapse. The second problem joins together the dynamics of a single bubble and the dynamics of a bubble system on the basis of the developed model of bubble cluster.

THE MATHEMATICAL MODEL OF A SINGLE VAPOR BUBBLE

To model the dynamics of a single bubble the spherically symmetric mathematical model is employed, which accounts for vapor and liquid compressibility, and also for heat and mass transfer [2]. Time interval from the moment of bubble nucleation till the final collapse is divided into two stages: slow or low Mach stage, at which the homobaric assumption for gas and incompressible liquid condition are used, and rapid stage, at which the set of differential equations presenting the laws of conservation of mass, momentum and energy is solved simultaneously for vapor inside the bubble and liquid outside it. The second stage, which is principal from the viewpoint of values of the achieved temperatures and neutron production is modeled on the basis of the equation of state in Mie–Gruneisen form with Born–Mayer potential.

THE EQUATIONS OF STATE OF ACETONE AND BENZOL

To describe and analyze the thermodynamic parameters of organic compounds on the basis of acetone and benzol a wide range equation of state is constructed, which gives satisfactory description of vapor and liquid phases. The well-known Mie–Gruneisen form of the equation of state is used as the sum of potential, or cold, and heat components of the internal energy and pressure. The derivation of the equation of state assumes a simplified approximation when the Gruneisen coefficient depends on density only and the heat capacity is set to be constant.

THE MATHEMATICAL MODEL OF BUBBLE CLUSTER ACCOUNTING FOR WAVE PROCESSES

To model the cluster dynamics the scheme is realized, which allows to investigate wave spreading in bubble liquid accounting for compressibility of carrying phase and high amplitude oscillations of the bubbles. To describe the wave processes a single–speed two–pressure model of the bubble system is introduced where the bubble oscillations are described by Rayleigh–Plesset equation with acoustic radiation. It is thought that the bubble medium placed inside the spherical cluster is centered in the limited spherical volume of compressible liquid, at which boundary the spherically symmetric acoustic field is produced. To describe parameters inside the bubbles the simple model is applied, which does not account for heat and mass transfer in phases and on the interface.

THE RESULTS OF NUMERICAL MODELING

On the basis of the mathematical model of single bubble and bubble cluster the numerical research of the bubble dynamics during acoustic cavitation in deuterated liquid is carried out.

As the basic variant the single vapor bubble is considered, which oscillates in deuterated acetone (C_3D_6O) influenced by a sinusoidal acoustic field with the amplitude of 15 bar and frequency of 19.3 kHz at liquid temperature to be 0 ^{o}C. It is shown that the bubble dynamics during slow stage is determined by the processes of heat and mass transfer in vapor and liquid. As acetone has high speed of evaporation and condensation (its accommodation coefficient $\alpha = 1$),

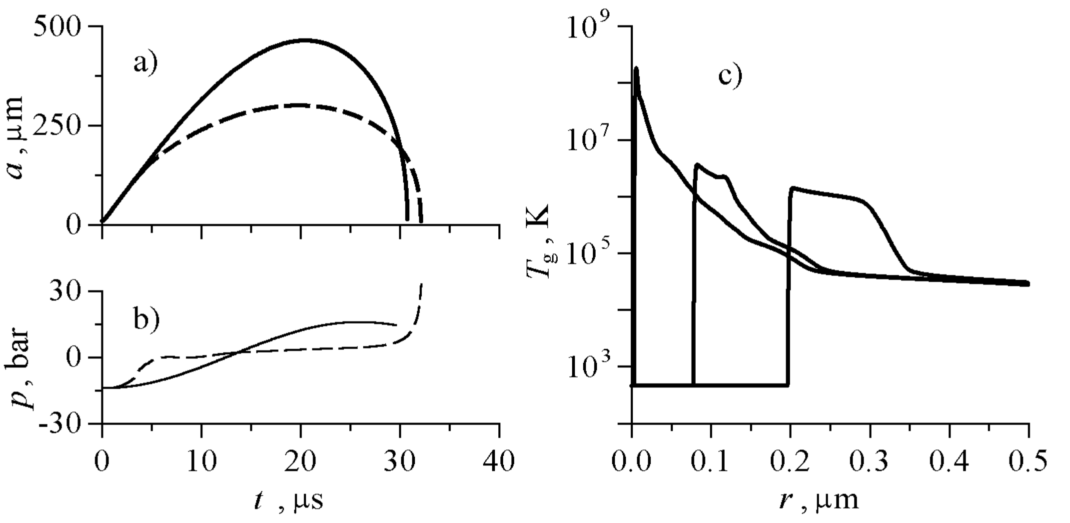

Figure 1. Bubble radius (a) and liquid pressure (b) evolution in time. Solid line – single bubble, dashed line – bubble in 20-bubbles cluster. Focusing of a shock wave near the bubble center (c).

the counterpressure of vapor in the bubble rises slowly, and this makes the collapse very intensive. During the rapid contraction the shock wave is formed inside the bubble (see Figure 1), which focusing in center leads to violent rise in density (10^4 kg/m^3), pressure (10^{10}–10^{11} bar) and temperature (10^8–10^9 K), high enough to produce nuclear reactions. The diameter of the neutron emission zone is about 100 nm with high peak at 3 nm. The average neutron number per collapse of the single bubble is estimated as 0.03 that gives about of 10^5 neutrons per second concerning the whole cluster.

The research of the influence of nucleation phase on the bubble dynamics in D-acetone is carried out. It is shown that the early bubble formation leads to the rise of radius change amplitude, which involves double increase in the number of emitted neutrons. The numerical investigation of positive pressure wave amplitude during bubble collapse is done. Two variants are considered: 50 and 100 bar, and it is obtained that the rise of compression amplitude leads to increase in speed of bubble contraction and, as the sequence, to enlargement of focusing shock wave. As compared with sinusoidal law the number of neutrons increases about ten times.

For three different liquid temperatures (253, 273 and 293 K) a comparative investigation of intensity of bubble collapse is conducted. It is obtained that the temperature decrease leads to the rise of the velocity of bubble contraction, but as the minimum radius also decreases the addition of the emitted neutrons becomes insignificant. The coagulation mechanism accompanied with additional enforcement at the contraction stage is considered. As the result of compression of the large gas volume the total number of emitted neutrons achieved the value of 1–2 per collapse.

The calculations with deuterated benzol (C_6D_6) are performed. It is posed that the collapse intensity and the matter heat up and also the number of emitted neutrons depend on the thermodynamic properties of the matter, in particular on the equation of state parameters.

The numerical simulation of the dynamics of vapor bubbles oscillating in the cluster dependent on the number of bubbles is carried out accounting for pressure waves evolution (see Figure 1). It is obtained that during the spreading of pressure waves in bubble liquid it is possible to get the enlargement of the amplitude that gives additional impulse during bubble contraction. The numerical calculations of the bubble dynamics in the cluster accounting for the pressure waves evolution and complex bubble model are carried out. It is shown that the collapse of the bubble in the cluster is less intensive compared with single bubble collapse. As the result of decrease in maximum and minimum values of bubble radius the shock wave, which leads to heat up of the matter in the bubble, becomes weak and causes the drop of the number of emitted neutrons of about 1–2 orders compared with single bubble.

References

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