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Method of superhigh resonant compression of a bubbly liquid by a moderate nonperiodical impact[1]

R. I. Nigmatulin, A. A. Gubaidullin, O. Sh. Beregova

Tyumen Branch of Institute of Theoretical and Applied Mechanics SB RAS, Tyumen

Abstract. In the present paper offered a method of processing a limited volume of a bubbly liquid by nonperiodical wave impact with a moderate amplitude, which results in originating of waves in the mixture, the amplitudes of which can by several orders exceed the amplitude of the initiating influence. The method is illustrated with the results of the direct numerical modeling.

Keywords: bubbly liquid, superhigh resonant compression, piston, bubble fusion, nonperiodical impact.

Several years ago there was discovered a phenomenon called sonoluminescence — the luminescence of gas bubbles in an acoustic field [1, 2]. This phenomenon is interesting not only from the scientific point of view, it can be usefully applied in various spheres of practical activity. For example, such a branch of chemical technology as sonochemistry has recently emerged owing to the sonoluminescence. The acoustic field, due to the high temperatures in the bubbles, can initiate certain chemical reactions, which are impossible in other conditions. But the most impressing is that in case of superhigh temperatures a thermonuclear reaction can start in the bubbles. The bubbles of deuterium in heavy water in case of superhigh compression can release the thermonuclear energy ("bubble fusion"). But the regular ultrasound is not sufficient for this.

A number of papers have been recently published [3–11] which are devoted to the theoretical description of the behaviour of a single gas bubble

[1] Работа была доложена на Международной конференции по многофазным системам, посвященной 60-летию академика Р. И. Нигматулина (15–17 июня 2000 года, г. Уфа)

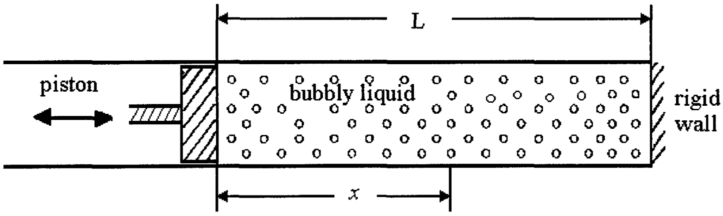

Figure 1: A scheme of excitation of bubbly liquid by a piston

oscillating in liquid under the impact of a wave field when the pressures and temperatures in gas may reach die extremely high values. The main idea of the new approach [7], called the "basketball regime" is coordinating the process of pressure alteration in liquid with the forced bubble oscillations and using the non-linear resonance in case of nonperiodical impact of the external pressure field with a moderate amplitude. In order to realize this idea a problem of spherically symmetrical oscillations of a gas bubble in a compressible liquid was raised and solved [8-10]. On the basis of die obtained analytical solution an effective computer code was worked out for mathematical modeling of a bubble collapse with due regard for various dissipative mechanisms such as viscosity, heat conductivity, radiation, ionization, wave processes around and inside the bubble, heat and mass exchange between the bubble and the surrounding liquid when the bubble is overcompressed.

Researching the processes occurring in a single collapsing bubble are undoubtedly an important and necessary stage, however the mentioned above applications are closely connected with the bubbly liquid — the mixture of a carrying liquid with a large number of bubbles dispersed in it

Let us consider a cylindrical volume of a bubbly liquid with the length L, limited by hard walls and a movable piston (Fig. 1).

The "basketball regime" of excitation of gas-liquid mixture is realized by setting the following boundary condition on the piston:

$$p_p = \begin{cases} p_{max}, & v_p \geq 0 \\ p_{min}, & v_p < 0 \end{cases},$$

where p_p, v_p are the pressure and velocity of the medium on tile piston. In such a situation, in the bubbly mixture there will propagate waves moving from the piston to the rigid wall, those reflected from the wall and returning to the piston, reflecting from it etc.

Let us make use of the bubbly liquid dynamic behavior model and methods of its computer realization presented in [12] for numerical investigation of the given problem.

Figure 2 presents the calculated dependencies on the period of pressure on the piston, velocity of the piston, and the gas pressure in bubbles in the middle of the volume ($x = L/2$) in the cases of the "basketball" and wave ($p_p = p_{max}$) regimes of excitation of the hydrogene-glycerine bubbly mixture with the parameters: $a_0 = 1$mm, $\alpha_0 = 2\%$, $T_0 = 293$K, $L = 20$cm, $p_0 = 10^5$Pa, $p_{max} = 1.2p_0$, $p_{min} = p_0$, $v_* = \sqrt{p_0/p_l}$, where a, α, ρ, T, p are the radius and volume content of the bubbles, density, temperature and pressure, correspondingly. The parameters of liquid and gas arc marked by the subscripts l and g, the initial values of the parameters are marked by 0. It is seen (Fig. 2) that when the piston moves in the "basketball" regime, the maximum gas pressure in the bubbles increases whenever the wave moves by for the next time, whereas when keeping the pressure on the piston constant (the wave of step-type) the gas pressure in the bubbles tends to be equal to the pressure on the piston.

Figure 2 affirms the theoretical possibility of excitation of the over-compression of the bubbly mixture by nonperiodical wave impact with a moderate amplitude.

The considered mechanical system has a resonance. By comparing the natural frequencies of this oscillatory system and those of the bubble oscillations in the mixture it is possible to define the parameters of the system at which the mode of excitation is resonant

The natural frequency of the system ω_S under the condition of wave excitation can be defined in the following way

$$\omega_S = \frac{2\pi}{T}, \quad T = \frac{L}{D_S} + \frac{L}{D_R},$$

where D_S, D_R are the velocities of the wave propagating from the piston and the wave reflected from the wall, correspondingly, the values of which in equilibrium approximation can be calculated according to the formulas

$$D_S = \sqrt{\frac{p_{max}}{\alpha_0 \rho_l}}, \quad D_R = \sqrt{\frac{p_R}{\alpha_S \rho_l}}, \quad p_R = \sqrt{\frac{p_{max}^2}{p_0}}, \quad \alpha_S = \alpha_0 p_0 / p_{max},$$

where α_S is the volume content of gas behind the falling wave, p_R is the pressure behind the wave reflected from the wall.

The natural frequency of the bubble oscillation in the mixture ω_R can be defined according to the formula

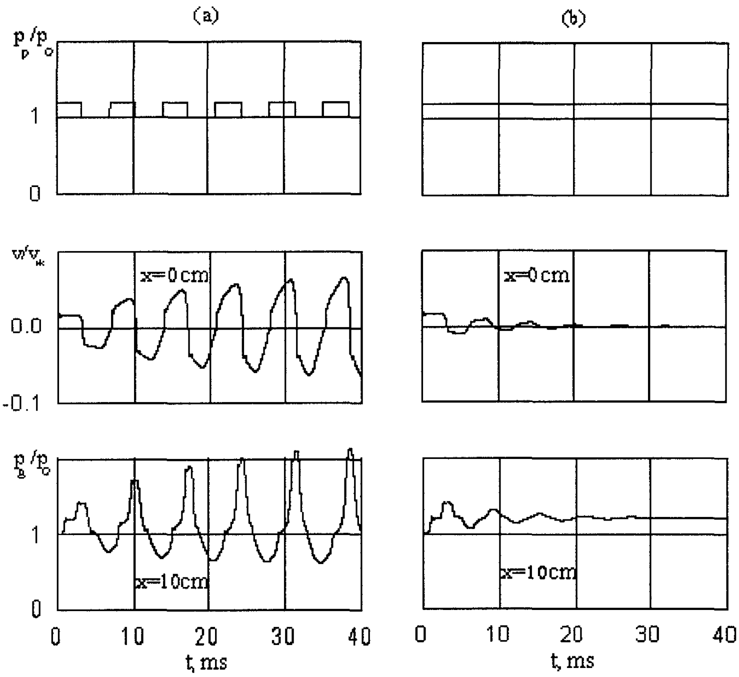

Figure 2: Profiles of liquid and gas pressure and piston velocity at "basket-ball" (a) and stationary (b) regimes of excitation of bubbly liquid

$$\omega_R = \frac{1}{a}\sqrt{\frac{3\gamma p_{max}}{(1-\phi)\,\rho_l}}, \quad \varphi = \frac{1.1\alpha_0^{1/3} - \alpha_0}{1-\alpha_0},$$

where γ is the adiabadc exponent of the gas, φ is the correction for the non-solitariness of the bubbles.

By equating the frequencies ω_S and ω_R it is possible to define the "resonant" values of the parameters. As seen from the formulas, the condition of the resonance will define one of the parameters (a_0, α_0, L, p_{max}) by the given values of the other parameters (when the liquid and gas are selected).

Figure 3 presents the calculated "scillograms" of the liquid pressure, gas pressure and temperature in the bubbles, radius and radial velocity of the bubbles, "registered" in the middle of the volume ($x = L/2$) when the air-water gas-liquid mixture with the parameters $a_0 = 1$mm, $\alpha_0 = 0.1\%$, $T_0 =$ 293K, $L = 5$cm, $p_0 = 0.1$MPa, $p_{max} = 1.5p_0$ is resonantly excited. It is seen

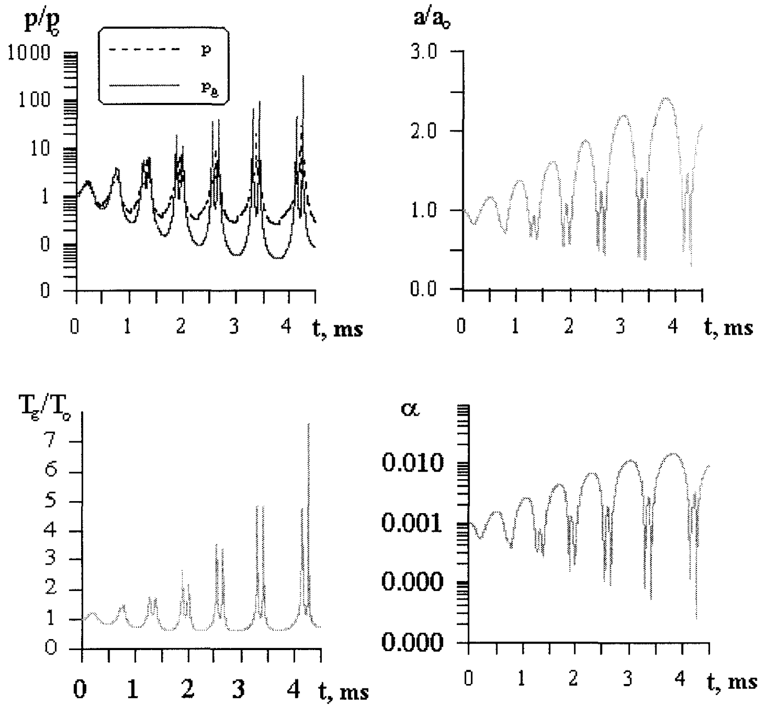

Figure 3: Profiles of pressures of liquid, gas, temperature and volume fraction of bubbles at resonance excitation

from the figure that in the present case the pressure amplitude is for two order higher than that of the initiating impulse, the amplitude of the latter being only 0.05 MPa. As this takes place, the gas temperature temporarily exceeds 2000 K. The temporal dependencies of the bubble radius a and the radial velocity w, as well as the volume concentration α show that the amplitude of their oscillations increases in the course of time.

The wave properties of a bubbly liquid are studied thoroughly enough. The behavior of the shock waves depends on the choice of the carrying phase (its density, viscosity) but it depends to a larger extent on the minor (not only in mass but also in volume) dispersed phase. The properties of gas in the bubbles, their size, character of the interphase heat exchange can principally influence the structure of the shock wave.

The accomplished numerical analysis showed that when the bubble radius decreases, the response of the bubbly mixture in the resonant excitation regime grows stronger. This complies with die result obtained in [10] for a solitary bubble.

Conclusion

A method of resonant excitation of a limited volume of a bubbly liquid by nonperiodical impact with a moderate amplitude, resulting in obtaining extreme gas pressures and temperatures in bubbles, is offered. The last mentioned feature is illustrated by the profiles of the pressure, temperature, bubble radius, etc., calculated within the scope of the one-velocity two-temperature with two pressures model of a bubbly mixture with a non-compressible liquid phase.

In order to obtain more precise quantitative information as applied to the concrete applications, e.g. to the problem of tile "bubble fusion", it is necessary to develop more complicated models of a bubbly liquid which would take into consideration various dissipative mechanisms such as compressibility of the liquid, radiation, ionization, wave processes outside and inside single bubbles, etc.

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