Detonation of a Bubble Chain in a Liquid

D.V.Voronin

Lavrentyev Institute of Hydrodynamics of SB RAS
pr. ac. Lavrentyeva, 15, Novosibirsk 630090, Russia
Ph.: (3832) 332-606; Fax: (3832) 331-612;
E-mail: voron@hydro.nsc.ru

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Numerical simulations of detonations of a bubble chain in a vertical channel filled with water or glycerin are performed. The flow-fields of main thermodynamic parameters have been calculated as in a liquid so within each bubble for a non-stationary, two-dimensional motion of compressible medium. The processes of possible bubble collapse, fragmentation, coalescence and distortion of a bubble form have been taken into account, and two-stage model of chemical kinetics have been used for gas phase. The critical conditions of detonations initiation and propagation along the chain have been determined. Comparison with experimental data confirms reliability of theoretical results.

The problem of detonation wave propagation in bubbly systems is of great interest for researchers since the phenomenon is used in many applications. A rise to experimental and theoretical research of the phenomenon had been given in the fundamental work [1]. For the chain of oxy-hydrogen bubbles in glycerin it was found that explosion of a single bubble may result in self-sustained wave propagation along the chain. Lately the problem has been studied in a number of works for various bubbly systems [2]. As a rule, numerical simulations are performed within the frame of mechanics of mutually penetrating continua, when there are both phases (gas and liquid) simultaneously at every point of the flow. This approach allows a researcher to operate with a great number of bubbles and obtain reliable results. But it has some disadvantages too. A bubble size must be considerably less than a size of computational cell, for example. Besides, a bubble dynamics behind a compression wave is very complicated. The processes of bubble growing, collapse, coalescence with other bubbles and distortion of a bubble form should be taken into account. The temperature and pressure flow fields are essentially non-uniform within a bubble. There may appear a local spots with abnormally high values of temperature [3], this effect determines character of a bubble ignition and explosion.

The present work is devoted to modeling of detonation wave propagation along a chain of bubbles. At each point of the flow only one phase is present. The flow fields of the main thermodynamic parameters have been computed within each bubble as well as in the outward liquid flow. Initial values of the flow parameters correspond to the experimental data [1]. The modeling has been performed within the frame of hydrodynamical approach for non-stationary two-dimensional axial symmetrical flow field. The set of governing equations is based on laws of conservation of mass, momentum and energy for a motion of ideal compressible medium. Borders between fluid and gaseous fragments were considered to be contact discontinuity surfaces, where the condition of pressure equality on different sides of the interface and the condition of continuity of velocity component, normal to the surface, are valid. The model of ideal gas is supposed to be valid for the bubbles. For the liquid the equation of energy conservation is replaced by ratios defining shock adiabatic curve (experimentally measured). The whole set of equations is formulated in [4].

The chemical reactions are supposed to take place only within the bubbles. The two stage model of the chemical kinetics was used, where behind the shock wave the induction zone is disposed with no energy release, followed by the zone of chemical reactions. In present paper the latter ones have been described by the chemical kinetics equation for mean molecular mass of the chemically reacting gas. The time of ignition delay corresponds to experimental results. The problem has been solved numerically with the help of method of individual particles.

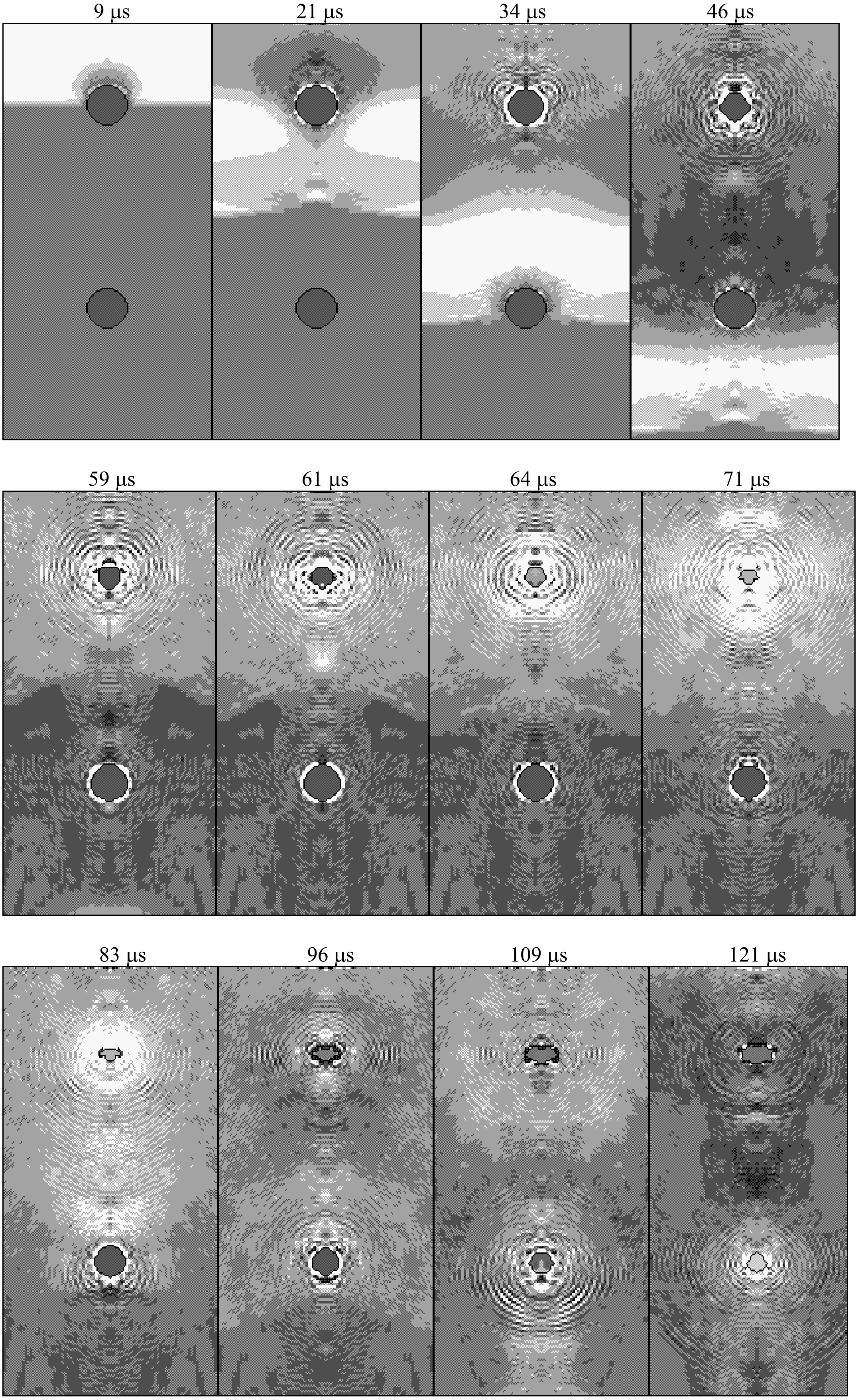

Fig.1. Dynamics of exploding bubbles behind a shock wave.

Results of some calculations of the mechanism of propagation of a detonation wave along a chain of bubbles are shown in figure 1. The background diagram of a pressure field in a vicinity of two bubbles for the various moments of time here is given. More light of tone in figure corresponds to waves of compression, and more dark corresponds to waves of rarefaction. The initiating wave is moving from the top to the bottom of each cadre. Initial bubble diameter here is equal to 10 mm, and the distance between their centers is equal to 50 mm. From figure it is visible, that in a shock wave the first from above bubble is compressed and loses the spherical form. On its surface nose is formed directed downwards. The collapse of the nose results in ignition of gas in the bubble (a luminous point in the first bubble at t = 61 μs). Though the great bulk of gas in the bubble quickly burns down, generating a secondary wave of compression, it is still possible to see areas of the unburned gas (so called "pockets") at t = 64 μs. The secondary wave of compression goes to the second bubble, partly compressed by the initial shock wave. Burning of the second bubble occurs similarly: ignition of a mix in collapsing nose takes place at t = 109 μs, and then explosion of gas in all the bubble occurs. After an explosion gas bubbles begin to extend and their size may exceed initial value essentially. The form of bubbles is far from spherical. The velocity of detonation wave propagation along a chain of bubbles, the mode of their form distortion coincides with experimental data [1]. Calculations of critical distances between bubbles and critical initial radius bubbles at which there comes attenuation of a wave are carried out also.

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