Shock Waves in Liquids with "Two-Phase" Bubbles

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Abstract
The propagation of shock waves in liquids with "two-phase" bubbles, containing heated solid particles is investigated. This question is connected with the problem of vapor explosions, when the liquid is boiling around heated particles.A mathematical model is used which takes into account both the liquid radial inertia due to medium volume changes, and the temperature distribution inside and around the bubbles. An analysis of the microscopic fields of physical parametersis aimed at closing the system of equations for averaged characteristics. The effect of the initial conditions, shock strength, volume fraction, and dispersity of the vapor phase and of the thermophysical properties of the phases on shock wave structure and relaxation time is studied. It has been established that an increase in the initial static pressure of the system, wave intensity and initial bubble radius, and a decrease in the initial void fraction lead to an increase in the distance of transition to the steady structure, as well as to an enhancement of the tendency towards oscillations in a wave.

Keywords - *bubbles, liquid, solid particle, shock wave.*

I. INTRODUCTION

Bubbly liquids have found widespread applications in conventional and nuclear power engineering, cryogenic technology and chemical engineering.

The distinctive features exhibited by a bubbly liquid in dynamic processes are connected with local deformation inertia, when the volume of the medium is changed owing to a change in the bubble volume, as well as with the elasticity of compression of the gas inside the bubbles. Liquid deformation inertia and gas elasticity of compression lead to bubble pulsation and, eventually, to oscillatory waves. Shock waves in bubbly liquids have been investigated theoretically and experimentally in the papers of many authors, reviewed in [1].

The more complicated situation when the bubble contains heated solid particle can arise as a result of accident in nuclear power station. This questionis connected with the problem of vapor explosions or thermal detonation when the liquid is boiling around heated particles [2].

In the present work the evolution of non-stationary shock waves of moderate intensities in a liquid with "two-phase" bubbles has been studied on the basis of the complete system of differential equations.

II. BASIC ASSUMPTIONS

Wave processes in a bubbly liquid are considered here using continuum mechanics methods under the following basic assumptions:

(i) the distances over which the flow parameters (for example,oscillatory wave lengths) vary significantly are much larger than the distances between the bubbles, which are themselves much larger than the bubble diameters (i.e. the volume fraction of the vapor phase is small enough, $a < 0.1$);

(ii) the mixture is locally monodispersed, i.e. in each material volume all the bubbles are spherical and of the same radius;

(iii) viscosity and thermal conduction are important only in the process of interphase interaction and in particular, in bubble pulsations;

(iv) the temperature distribution inside solid particle is uniform;

(v) nucleation, fragmentation, interaction and coagulation of the bubbles are absent;

(vi) the velocities of the macroscopic motion of the phases coincide.

The last assumption allows us to describe bubble volume changes, temperature distributions inside and around the bubbles, condensation and evaporation in terms of the spherically symmetrical model using the equations for bubble radial pulsations and radial thermal conduction of vapor and liquid. This assumption originates from the fact that for vapor bubbles two-velocity effects are less significant on the background of thermal dissipation.

Under the assumptions listed above the solid-liquid-vapor medium can be considered within the framework of a model of interacting and interpenetrating continuous media, viz the carrier liquid and disperse phase [3].

For numerical solution of the problem we used the equations of conservation of mass, bubble number density and of momentum of the mixture for one-dimensional motion.

The system of hydrodynamic equations can be closed if the equation of state,the condition of the simultaneous deformation of the phases and the equation for determining the phase transition rate are assigned. The evolution of pressure waves of moderate intensities can be considered under the following additional assumptions:

(a) the carrier liquid is incompressible;

(b) the vapor obeys the equation of state of prefect gas, and being in the saturated state at the interface it obeys the Clapeyron—Clausius equation.

In this case the mixture is compressed at the expense of the compression of the vapor in the bubble.

Transfer processes in a multiphase mixture are determined by the distributions of microparameters near inhomogeneities. For an analysis not to be too complicated, one has to make use the models that could considerably simplify the microprocess equations. A possible model is one that employs the concept of a cell with a test bubble in it at any point of the space. The cell dimension is determined by the volume fractions of the phases; the cell center coinciding with the center of the test bubble. This cell moves with the macroscopic velocity of the disperse phase at the point considered. The distributions of microparameters inside a cell are described by the equations for the corresponding microprocesses with the boundary conditions on the test bubble surface (which determine theinterphase interaction) and on the external boundary of the cell. The vapor and liquid at the interface are assumed to be in thermodynamic equilibrium. The phase transition rate may be found from the boundary conditions on the bubble surface. In the absence of a macroscopic heat flux in the carrier the condition on the cell boundary should reflect the cell adiabaticity.

An analysis of the microscopic fields of physical parameters is aimed at closing the system of equations for averaged characteristics.

It should be noted that an allowance for the microparameter distributions makes the solution to the problems of wave dynamics in bubbly liquids much more difficult. Even the simplified account of the temperature microdistribution inside and around the bubbles for a one-dimensional unsteady flow (under the assumption of a spherical symmetry of the microprocess) considered here leads to the necessity of solving a system of partial differential equations in three independent variables.

III. DISCUSSION OF THE RESULTS

The main regularities of the propagation of plane non-stationary shock waves and the evolution of pulse disturbances in liquids, containing heated iron particles were studied. The effect of the initial conditions, shock strength, volume fraction and dispersity of the vapor phase and of the thermophysical properties of the phases on shock-wave structure and relaxation time was investigated. It has been established that an increase in the initial static pressure of the system, wave intensity and initial bubble radius, and a decrease in the initial void fraction lead to an increase in the distance of transition to the steady structure, as well as to an enhancement of the tendency towards oscillations in a wave. The damping of the delta-pulse strongly depends on its initial duration. More intense and longer pulses exhibit a lower damping. During the evolution of the delta-pulse as well as during the propagation of non-steady shock waves the effect of pressure increase in the mixture, as compared to the initiating pressure, is observed.

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