Instability in Acoustics of Liquids with Soluble Gas Bubbles

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Abstract

The effect of gas solubility on the oscillation characteristics of bubbles in an acoustic field, the propagation and damping of perturbations in bubbly mixtures and moreover, the stability of such media is analyzed analytically and numerically. It is shown that the combined action of capillarity effects and the solubility of the gas essentially determine the behavior of bubbly gas-liquid mixtures. In particular, such mixtures may be unstable, the instability usually appearing in the case of finely dispersed mixtures: In some cases the phase velocity for low frequencies tends to infinity and the damping factor to zero. This, generally speaking, is a sign of instability.

Keywords: *bubbles, solubility, instability, waves*

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 [1].

In the present work the propagation of small perturbations in liquid with soluble gas bubbles has been studied on the basis of the complete system of differential equations. For describing the propagation of acoustic perturbations in a liquid containing bubbles of dissolved gas with allowance for unsteady interphase heat and mass transfer it is possible to employ a one-velocity two-pressure model of the medium that takes into account the radial inertia of the liquid with change in the volume of the medium and the temperature and concentration distributions [1].

The propagation of small perturbations in gas-liquid media without allowance for the solubility of the gas in the liquid has been examined in a series of studies (for a review see for example [2]).

II. BASIC ASSUMPTIONS

We will consider the propagation of small perturbations in a liquid containing gas bubbles under the following main assumptions [3]: the mixture is locally monodisperse, i.e., in each volume element all the bubbles are spheres of the same radius: viscosity and heat conduction are important only in the interphase interaction process and in particular, in connection with the pulsations of the bubbles; the translational motion of the bubbles relative the liquid is unimportant; the wave length is much greater than the distances between bubbles, which in their turn are much greater than the size of the bubbles, i.e., the volume gas content is fairly low; there are no bubble generation, breakup or coalescence processes .

Under the assumptions listed above the gas-liquid medium can be considered within the framework of a model of interacting and interpenetrating continuous media, viz. the carrier liquid and disperse phase [1]. For 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 equations for determining the heat and mass transfer rate are assigned. The liquid carrier phase is assumed to be compressible, and the changes in bubble volume and in the concentration and temperature distributions around and inside the bubbles and the diffusion and heat conduction processes are described within the framework of a spherical symmetric model using the equation of the radial pulsations of the bubble.

Transfer processes in a multiphase mixture are determined by the distributions of micro parameters near inhomogeneties. 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 each macroscopic point of the medium we introduce a spherical cell with a "test": macroscopic point of the medium we introduce a spherical cell with a "test" bubble at its center and surrounding liquid. The size of the cell depends on the volume gas content. The center of the test bubble and the cell coincide and move with the macroscopic velocity of the gas phase at this point. The microscopic parameters inside and around the ‘test bubble are assumed to depend on time, the position of the center of the “test” bubble or the cell, and the distance of the micro particle from the center (in the coordinate system moving with the bubble the micro parameters within the bubble depend only on time and the distance from the center of the bubble). The distribution of the micro parameters within and around the “test” bubble is described by the equations of the corresponding microprocesses, the boundary conditions at the surface of the “test bubble also determining the rate of the interphase heat and mass transfer in the medium. An investigation of the microfields of the physical parameters serves to close the system of equations for the average characteristics.

It should be noted that an allowance for the micro parameters distributions makes the solution to the problems of wave dynamics in bubbly liquids much more difficult. Even the simplified account of the temperature and concentration micro distribution inside and around the bubbles for 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

We considered the propagation of small perturbations in a gas-liquid bubbly mixture on the assumption that the angular frequency of the perturbation is given. We seek the solution of the system in the form of a damped traveling wave. From the condition of existence of a solution of this form we have the dispersion relation. It is shown that the combined action of capillarity effects and the solubility of the gas essentially determine the behavior of bubbly gas-liquid mixtures. In particular, such mixtures may be unstable, the instability usually appearing in the case of finely dispersed mixtures. In some cases the phase velocity for low frequencies tends to infinity and the damping factor to zero. This, generally speaking is a sign of instability.

It is shown that as a result of the combined action of the gas solubility and capillary effects, the small radially symmetric oscillations of gas bubbles in an acoustic field are unstable in amplitude. Expressions are obtained for the decay rate of the radial oscillations of the gas bubble and the increment characterizing the rate of increase of oscillations amplitude in the region of instability. It is shown that the damping rate of the free oscillations of a soluble gas in a liquid is directly proportional to the Henry constant. However, in investigating the oscillations of bubbles full of gases readily soluble in water such as ammonia, hydrogen chloride and sulfur dioxide, it is necessary to take into account the kinetics of the accompanying chemical reactions and the heat released.

The analyses of dispersion relation shows that this relation always has complex-conjugate roots corresponding to damped traveling waves propagated in opposite directions. In some cases the dispersion equation also has a positive solution and this means that the amplitude of the distributed perturbations increases with time, i.e., the equilibrium state of the two-phase medium is unstable. From an analysis of the dispersion relation it is clear that the wave number varies from zero to infinity, the growth rate of increment increases from zero to a certain maximum.

In order to establish the nature of the instability mechanism, we considered a certain hypothetical two-phase bubbly medium whose liquid phase is a solvent with a value of the diffusion coefficient equal to infinity. It is shown that this hypothetical ideal medium responds to an attempt at compression with a decrease in pressure and hence is unstable. If for this hypothetical ideal medium the relation between the growth rate and the wave number is linear, then taking the radial inertia, viscosity and diffusion into account leads to disturbance of the linearity without affecting the region of instability. The rate of development of the instability is limited by the diffusion process.

IV. CONCLUSIONS

The propagation of acoustic waves in liquids containing soluble gas bubbles has been studied on the basis of the complete system of differential equations. An analysis of the microscopic fields of physical parameters is aimed at closing the system of equations of averaged characteristics. It is shown that the combined action of capillary effects and the solubility of the gas essentially determine the behavior of bubbly gas-liquid mixtures. In particular, such mixtures may be unstable, the instability usually appearing in the case of finely dispersed mixtures. In some cases the phase velocity for low frequencies tends to infinity and the damping factor to zero that is a sign of instability.

REFERENCES

[1]. Khabeev R.N., Khabeev N.S. Stability of oscillations of soluble gas bubbles. Journal of Engineering Physics and Thermophysics, Springer, 2019, N 2.

[2]. Shagapov V.S., Khabeev N.S. et al. Acoustic waves in a liquid with bubble screen, International Journal on Shock Waves, 2003, v.13, N 1 , Springer

[3]. Nigmatulin R.I. Dynamics of Multiphase Media, Hemisphere, Washington D.C., 1990