CALCULATION OF THE INTERACTION BETWEEN PRESSURE WAVES AND A TARGET IN THE PRESENCE OF A FOAMY SHIELD

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The interaction between pressure waves and a nonuniform gas-liquid shield with a foamy structure near a rigid wall is studied within the framework of a discrete foam model with allowance for bubble pulsations. Calculation results are compared with the available experimental data.

The interaction between shock waves (SW) and a foam shield was previously studied mainly using experimental techniques [1-6]. It should be noted that the physical experiment is often not informative enough. In particular, the pressure values at various points of a shock tube and the position of the contact boundary and its velocity were recorded in experiments, while many other important parameters remained undetermined. In some cases, the limited experimental data do not allow a complete restoration of the interaction pattern. The numerical experiment is free from this shortcoming. In this case, we have to use simplified models which, nevertheless, allow us to gain a more penetrating insight into the physics of the processes.

Rudinger's equilibrium model of a two-phase medium [7] in which a foam was replaced by a pseudogas with an effective adiabatic exponent is widely used in studying the propagation of pressure waves in foams. In this case, the values of the pressure of a SW reflected from a rigid obstacle appeared to be much larger than experimental ones [8]. In addition, some other shortcomings of the Rudinger model are noted in [9].

Adopting a law of independent compressibility of the medium's components and ignoring the heat and mass transfer processes, one obtains Rakhmatulin's closed model for a two-phase medium [10] used in [9, 11]. Calculation results obtained by this model are in good agreement with the available experimental data, including the problems of SW reflected from rigid walls. However, using the model for calculation of the interaction between unsteady pressure waves and nonhomogeneous foams is complicated, since there is no complete solution of the problem of arbitrary-discontinuity decay for this model. This problem is used either directly in numerical schemes like Godunov's method or in terms of the boundary conditions. It should also be noted that the values of pressure calculated by this foam model are somewhat overestimated, because bubble pulsations induced by passing SW are ignored [11].

Various modifications of the discrete model in which the complex foam structure was replaced by a simplified one were used in [9, 11, 12] to study wave propagation in a foam. However, the pulsatory character of the interaction was taken into account.

FORMULATION OF THE PROBLEM

We consider the interaction between a SW and a layer of nonuniform foam of thickness $h$, which is positioned near the lower edge of a vertical shock tube. The input data for calculations correspond to the experimental conditions of [6]: $h = 19$ cm, the main channel of the tube is 1.44 m long, and the high-pressure chamber is 0.8 m long. Pressure gauges are placed at distances of 1.87, 1.98, 2.10, and 2.24 m from the coordinate origin, which is the upper edge of the high-pressure chamber. The air pressure in the main channel...
and in the high-pressure chamber is 1 and 4.8 atm ($\gamma = 1.4$), respectively. Upon rupture of the diaphragm under these conditions, a SW incident on the foam is formed. The SW parameters correspond to those in the experiment of [6]. In particular, the Mach number in the incident SW equals 1.39.

Calculations were performed within the framework of a "layer-by-layer" scheme; instead of the two-phase medium, a discrete system of alternating liquid and gas layers was employed. This foam model is a simple but efficient tool for studying flows of gas–liquid media in the one-dimensional formulation and, in particular, in shock tubes [9].

It is known that as a consequence of syneresis, the foam in the gravity field is nonuniform in height [2]. The foam nonuniformity in the initial state was simulated by varying the thickness $\delta_i^f$ of liquid layers composing the foam (i is the ordinal number of the layer). The thickness of the gas layer $\delta_g$ prior to the interaction was assumed to be constant.

Curve 2 in Fig. 1 shows the local foam density $\rho_f$ vs. the layer thickness $\delta$ which is calculated by the relation

$$\rho_f(\delta) = a + b\exp(d\delta),$$

where $a = -4$, $b = 11.9$, $d = 0.01$, and $\delta$ is given in meters. The values of the coefficients are selected so that the mean foam density was 32 km/m$^3$, as in [6].

The dependence of the effective thickness of liquid layers $\delta_i^f$ (curve 1 in Fig. 1) on the longitudinal coordinate $\delta$ corresponding to curve 2 was determined from the expression [9] $\delta_i^f = \rho_i^f\delta_g/((\rho_0\rho_i + \rho_1 - \rho_i^f)$, where $\rho_i^f$ is the physical density of the liquid (for a water foam, $\rho_0 = 1000$ kg/m$^3$) and $\delta_g = 1$ mm.

In the context of this approach, gas flow beyond the foam layer was calculated in movable meshes by the Godunov method [13], while the motion of liquid layers under the action of the pressure difference in adjacent foam layers was calculated by numerical integration of the system of $N$ ordinary differential equations

$$\rho_i\delta_i^f\frac{d\dot{u}_i^f}{dt} = p^f - p^{i-1},$$

where $\dot{u}_i^f$ is the velocity of the $i$th liquid layer, $p^f$ and $p^{i-1}$ are the values of the pressure on the different sides of the $i$th layer, and $N$ is the total number of liquid layers composing the foam. In the above equations, we ignored the inertia of gas in the cells and phase transformations. The processes in gas layers were assumed to be adiabatic. Therefore, the current values of pressure $p^f$ and gas density $\rho_g^i$ in the $i$th gas layer are related to the initial $p_0$ and $\rho_0$ by the relation $p^f = p_0(\rho_g^i/\rho_0)^\gamma$. 

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**Fig. 1. Distributions of the effective thicknesses of liquid layers (1) and of the foam density (2) across the layer.**