At high temperatures $\alpha = 2/3$ and

$$F(\alpha) = \frac{5}{3}.$$

Thus, the hydrodynamic velocity (23) arising at the initial time proves to be proportional to the third power of the temperature gradient, which permits one to ignore it in a linear approximation in problems of the kinetic theory of gases and in the physics of aerosols [2].

LITERATURE CITED

1. S. Chapman and T. G. Cowling, The Mathematical Theory of Non-Uniform Gases, 2nd ed., Cambridge University Press, London–New York (1952).
2. Yu. I. Yalamov, Author's Abstract of Doctoral Dissertation, Moscow (1968).

UTILIZATION OF LIQUID–GAS BUBBLE MIXTURES FOR THE TRANSFER OF SHOCK-WAVE DISTURBANCES

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UDC 532.546

Transfer of the energy of shock-wave disturbances from a gas to a liquid or to a liquid–gas bubble mixture is considered. It is shown that the energy flux from the gas increases when a liquid with gas bubbles is substituted for the pure liquid.

Liquids have been used for a long time as the transmission medium for transmitting pressure from a gaseous medium to a certain object. For pressures at the wave front amounting to several hundreds of bars, most liquids behave as incompressible liquids. Therefore, as a shock wave from the gas reaches the liquid surface, the liquid receives only a weak acoustic wave carrying a small amount of stored energy, while most of the energy remains in the wave reflected from the liquid surface.

One of the possible ways to increase the percentage of the shock-wave energy transmitted to the liquid is to use a liquid mixed with gas bubbles as the transmission medium.

It is known [1] that the ratio of the wave energy flux in the liquid E_2 to the wave energy flux in the gas E_1 is determined by

$$\frac{E_2}{E_1} = \frac{4\rho_1 c_1 \cdot \rho_2 c_2}{(\rho_1 c_1 + \rho_2 c_2)^2}.$$

In this expression, ρ_1 and c_1 are the density and the sound velocity in the gas; and ρ_2 and c_2 are the density and the sound velocity in the liquid. If the acoustic resistances of two media are equal, complete transfer of energy from one medium to the other occurs, i.e., $E_2 = E_1$. If the acoustic resistance of one medium is much higher than the resistance of the other, we have $E_2 \ll E_1$ as the wave passes from the medium characterized by $\rho_1 c_1$ to the medium characterized by $\rho_2 c_2$. For instance, in the frequently encountered case of shock-wave transition at the air–water interface, $E_2 \approx 10^{-3} E_1$.

It is evident from the above relationship that the value of E_2 can be increased by reducing the density and the velocity of sound in the medium with the parameters $\rho_2 c_2$. For this, it is sufficient to use a liquid with gas bubbles instead of the pure liquid. For a liquid volume concentration up to 80%, the density of the two-phase medium ρ will change slightly, since

Institute of Chemical Physics, Academy of Sciences of the USSR, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 31, No. 4, pp. 674-677, October, 1976. Original article submitted September 5, 1975.

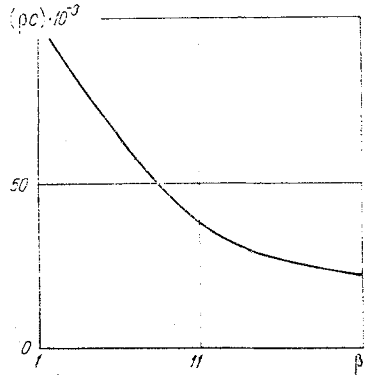

Fig. 1. Acoustic resistance of a two-phase medium as a function of the volume concentration of gas β, %.

$$\rho = \rho_2(1-\beta) + \beta\rho_1,$$

where β is the volume percentage of the gas. Hence, for $\beta \ll 1$ and $\rho_1 \ll \rho_2$, it follows that $\rho \approx \rho_2$.

The situation is completely different with regard to the propagation velocity of weak long-wave pressure disturbances, which can be considered as the velocity of sound. In accordance with the data given in [2], the velocity of sound in a mixture of a liquid and gas bubbles can be determined by means of the relationship

$$c^2 = p[\beta\rho(1-\beta)]^{-1}.$$

Even for a gas concentration $\beta = 10^{-2}-10^{-1}$, the calculated velocity is much lower than the velocity of sound in a liquid without bubbles. As a result of a reduction in the sound velocity, the acoustic resistance of the medium decreases from $1.5 \cdot 10^6$ kg/m$^2\cdot$sec for water to 10^5 kg/m$^2\cdot$sec if $\beta = 0.01$ and 10^4 kg/m$^2\cdot$sec if $\beta = 0.2$ for the gas–liquid medium. Figure 1 shows the acoustic resistance as a function of the percentage of gas bubbles in the liquid.

As a result of the considerable reduction in the acoustic resistance, the share of the shock-wave energy which is transmitted to the gas–liquid medium increases. Figure 2a shows the ratio of the energy flux in a wave that has passed into the gas–liquid medium to the energy flux in the wave in the gaseous medium K_1, as a function of the gas percentage in the gas–liquid medium. It is readily seen that $K_1 \approx 10^{-3}$ if an air shock wave impinges on water, and $K_1 \approx 17\cdot 10^{-3}$ for $\beta = 0.01$ and $K_1 \approx 69\cdot 10^{-3}$ for $\beta = 0.2$ if this wave impinges on a gas–liquid medium, i.e., the energy flux in the last case has increased by a factor of 69.

Let us now consider the passage of the shock-wave disturbance from a gas–liquid medium to a pure liquid. Figure 2b shows the ratio of the energy fluxes in the passing and the incident waves K_2 as a function of the percentage of gas in the gas–liquid medium. The diagram indicates that the amount of energy transmitted to water decreases as the gaseous phase concentration in the liquid increases.

In conclusion, we shall analyze the case when a pressure wave first impinges on the surface of a two-phase medium and then passes from the latter to a "pure" liquid. The relationship between the energy fluxes in the passing and the incident waves is given by $K_3 = K_1 \cdot K_2$. The graph illustrating the behavior of K_3 is given in Fig. 2c.

Analyzing the above dependence, we see that the energy flux in the passing wave increases by a factor of almost four if a two-phase layer is used.

This investigation shows that a mixture of gas bubbles and a liquid ensures a larger energy flux in the wave that passes into the liquid. Therefore, it is often more advisable to use a two-phase medium as an energy transformer for air shock waves [3]. Thus, it has been demonstrated in [3] that the pressure beyond a reflected shock wave is much higher in a gas–liquid medium than in a continuous medium.

The above description is based on analysis of the disintegration of an arbitrary discontinuity where the wavelength and the length of the section of the gas–liquid medium are infinite. In actual cases, it is advisable

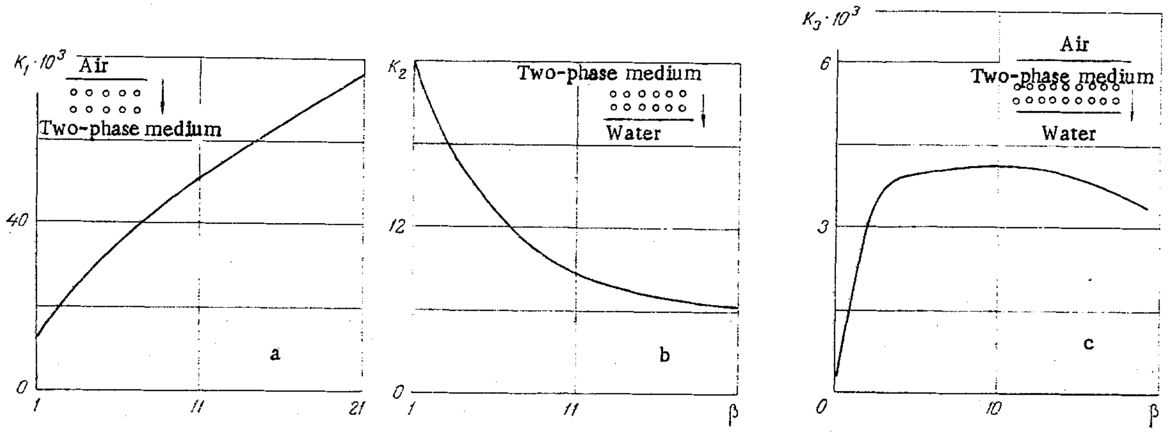

Fig. 2. Coefficient of energy transfer from air to water (a) from a two-phase mixture to water (b), and from air to water through a layer of a two-phase mixture (c) as a function of the volume concentration of gas in the layer.

to consider only lengths of the order of 1 m. It has been established experimentally that the effect of pressure increase in reflection takes place even if the column of the two-phase medium has a length of 0.5-1 m [4]. It was also shown in [3, 4] that shock-wave damping due to energy dissipation does not occur at a wavelength of 0.5-1 m. The gain in pressure beyond the reflected shock wave is made possible by the absence of significant energy dissipation.

NOTATION

E	is the energy flux;
ρ_1	is the gas density;
ρ_2	is the density of the liquid;
c_1	is the sound velocity in the gas;
c_2	is the sound velocity in the liquid;
c	is the sound velocity in the two-phase medium;
p	is the pressure;
β	is the volume concentration of the gas;
K_1, K_2, K_3	are the coefficients.

LITERATURE CITED

1. L. M. Brekhovskikh, Waves in Laminar Media [in Russian], Izd. Akad. Nauk SSR (1957).
2. G. A. Saltanov, Supersonic Two-Phase Flow [in Russian], Vyshéishaya Shkola, Minsk (1972).
3. B. E. Gel'fand, S. A. Gubin, S. M. Kogarko, and B. S. Kogarko, Dokl. Akad. Nauk SSSR, 213, No. 13 (1973).
4. B. E. Gel'fand, S. A. Gubin, S. M. Kogarko, and E. I. Timofeev, Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No. 6 (1974).