CALCULATION OF THE ENERGY OF A SHOCK WAVE IN WATER

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ABSTRACT: The energy radiated to the shock wave in an underwater explosion is found in terms of the energy of the irreversible losses in the shock wave and the mechanical energy of the shock wave.

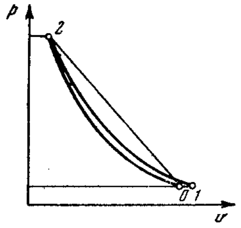

Fig. 1

The dissipation of energy in a shock wave in water has been determined with the help of the adiabatic equation of state, the isentropic unloading curves and the dependence of the pressure at the shock front on distance. For the underwater explosion of a spherical charge the total irreversible energy loss E_1 in the shock wave is

$$E_1 = \frac{4\pi}{v_0} \int_{r_0}^{r} e(p_2) r^2 dr, \qquad (1)$$

where the specific energy loss $e(p_2)$ is equal to [1]

$$e(p_2) = \frac{p_2 + p_0}{2} (v_0 - v_2) - \int_{v_2}^{v_1} p\, dv. \qquad (2)$$

Here p_0, v_0 are the initial pressure and specific volume of the water, $p_2(r)$, $v_2(r)$ are the pressure and specific volume of the water at the shock front, r is the coordinate of the shock front, and r_0 is the radius of the charge.

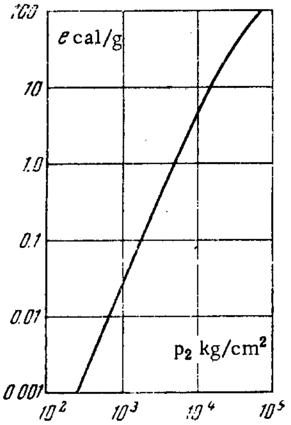

Fig. 2

The integral in Eq. (2) is evaluated along the isentropic curve of expansion of water 12 (Fig. 1) to the volume v_1, which corresponds to the state of the water after expansion to the initial pressure p_0.

To evaluate E_1 it is necessary to know the adiabatic equation of state of water, the isentropic unloading curves and the dependence of the pressure at the shock front p_2 on distance r.

To calculate $e(p_2)$ (Fig. 2) we used the adiabatic equation of state of water [3]

$$p = 3045\, [(v_0 / v)^{7.15} - 1] \qquad \text{at } p_2 \leqslant 25 \cdot 10^3 \text{ kg/cm}^2.$$

For $p_2 > 25 \cdot 10^3$ kg/cm^2 we used the equation of state and unloading isentropes of [2]. Relations between the pressure $p_2 r^\circ \times 10^{-3}$ kg/cm^2 and the dimensionless distance $r^\circ = r/r_0$ are given in Fig. 3, where curve 1 is for pentolite [3] and curve 2 for PETN of density 1.6 g/cm^3 [4].

When $e(p_2)$ is calculated for the explosion of charges in solids it is possible to consider that the equation of state and the isentropic unloading curves coincide [5], in the case of explosions in air it is necessary to allow for the processes of ionization and dissociation.

The energy Q of the explosion in water of unit mass of charge (heat of explosion) is

$$Q = E + \Pi \qquad (E = E_1 + E_2).$$

Here Π is the energy of the gas bubble pulsations, E is the energy radiated to the shock wave, and E_2 is the mechanical energy in the shock wave, which is usually obtained from empirical formulas [3, 4].

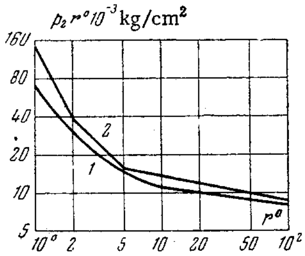

Fig. 3

Curve 1 of Fig. 4 represents the relation $\eta_1 = E_1/Q$ for pentolite (r_0 = 25.4 mm) and curve $2\eta_2 = E_2/Q$ as a function of r° calculated from the formula [3]

$$E_2 = 106.3 \cdot 4\pi r^2 G^{1/3} \left(\frac{G^{1/3}}{r}\right)^{2.12}$$

(G is the weight of the charge).

The difference $\eta = 1 - (\eta_1 + \eta_2) = \Pi/Q$ shows what part of the energy of the explosion is left for the bubble pulsations after radiation of the shock wave. For the given case η = 0.41–0.43 and E/Q = = 0.57–0.59 at $10 < r^\circ < 25$ (Fig. 4).

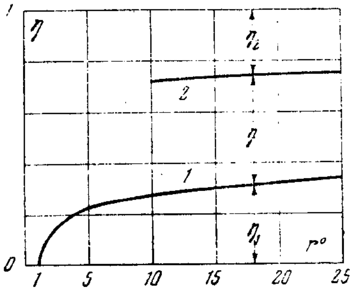

Fig. 4

Calculations of the irreversible energy loss in a shock wave in water following the explosion of spherical charges of PETN of various density ρ yield the following values:

$$E / Q = 0.77\ (0.6), \quad \Pi / Q = 0.23\ (0.4) \quad \text{at } \rho = 1.6 \text{ g/cm}^3,$$
$$E / Q = 0.47\ (0.44), \quad \Pi / Q = 0.53\ (0.56) \quad \text{at } \rho = 0.4 \text{ g/cm}^3.$$

The figures in parentheses are the values of E and Π obtained in [4] by extrapolation of the energy curve to $r^{\circ} = 1$.

For a low-density charge ($\rho = 0.4$ g/cm^3) the different methods of calculation give practically the same result, but for charges of density $\rho = 1.6$ g/cm^3 the difference is substantial.

Note also the difference in the results of calculations for pentolite and PETN ($\rho = 1.6$ g/cm^3), which is attributable to the large divergence of the experimental values of the pressure in the shock wave [3, 4] close to the charge.

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