Blast Waves Produced by Underwater Gaseous and High Explosive Detonations

Oleg Popov, Gennady Agafonov, Boris Gelfand

N.N. Semenov Institute of Chemical Physics, Russian Academy of Science,
Kosygin street 4, Moscow, 119991, Russia

1 Introduction

Early investigations of underwater exposions [1] have chiefly been confined to the studies of intense explosions generated by high-energy sources, such as HEs (TNT, PETN and others). It follows from [2] that the principle of energy similarity is not satisfied for underwater explosions of high explosives, and the pressure-wave parameters do not only depend on the energy of the explosion source but also on the volume energy density. It is natural to expect significant spoilage of the energy similarity especially in the comparison of explosion waves from gaseous and solid high explosives whose volume energy density can differ by three orders of magnitude.

The objective of this work is to compare of blast wave parameters (the pressure amplitude, specific impulse, time constant) for the gaseous and TNT detonations at varying energies and distances. A pressure-impulse diagram is used to estimate the shock wave impact to marine ichthyofauna.

2 Blast wave parameters of TNT

The results of measurements of blast wave parameters obtained in [3] for detonation of gaseous mixtures (C_3H_8+$5O_2$) in water permit their comparison with known data for TNT [1].

It is also interesting to determine the degree of deviation from energy similarity at different distances from the site of the explosion and from the magnitude of the volume energy density of the gas mixture. This latter can vary because of the dependence of the gas density on the depth of submersion of the charge.

The relationships for the fundamental wave parameters measured at a distance r from the center of the explosion with energy W are expressed in terms of the scaled distance $R_w^0 = r / W^{1/3}$, where R_w^0 is in m/MJ$^{1/3}$. In this case the interpolation formulas [1] for TNT can be represented in the form

$$p = 305 \cdot 10^5 / (R_w^0)^{1.13},$$

$$I / W^{1/3} = 2.33 \cdot 10^3 / (R_w^0)^{0.89},$$

here p is the peak pressure, Pa ; I is the specific impulse, Pa·s . The formulas mentioned describe the experimental data for $0.26 \le R_w^0 \le 8.21$, which corresponds to relative distances $7.7 \le r / R \le 245$ from the center of the TNT charge. A correlation for the wave time constant θ (msec) in [1] can be approximated by a power law

$$\theta / W^{1/3} = 0.0697 (R_w^0)^{0.24}.$$

Correspondence to : popov@chph.ras.ru

3 Pressure wave parameters of gaseos explosions

The underwater gaseous explosions have been investigated in detail in [3-6]. It follows from [3] that

$$\Delta p = 0.149 \cdot q^{2/3} / R_w^0 \ .$$

This relationship is valid for $r/R_0 > 2\text{-}3$, where R_0 is the initial radius of the charge, and q is the volume energy density (the energy per unit volume), mJ/m^3. In particular , for a gas mixture with q=7.2 MJ/m^3, the relationship

$$\Delta p = 5.56 \cdot 10^5 / R_w^0$$

describes the experimental results for the mixture C_3H_8+$5O_2$ with the initial pressure 10^5 Pa.

The peak pressures in explosion waves of the gas mixture C_3H_8+$5O_2$ and TNT are compared in Fig. 1. Although the energy similarity is indeed not satisfied, nevertheless, the selected coordinate system permits showing how the pressures in the waves differ for equal energies being liberated. The charge surface of the explosive gas mixtureis denoted by the dashed vertical line.

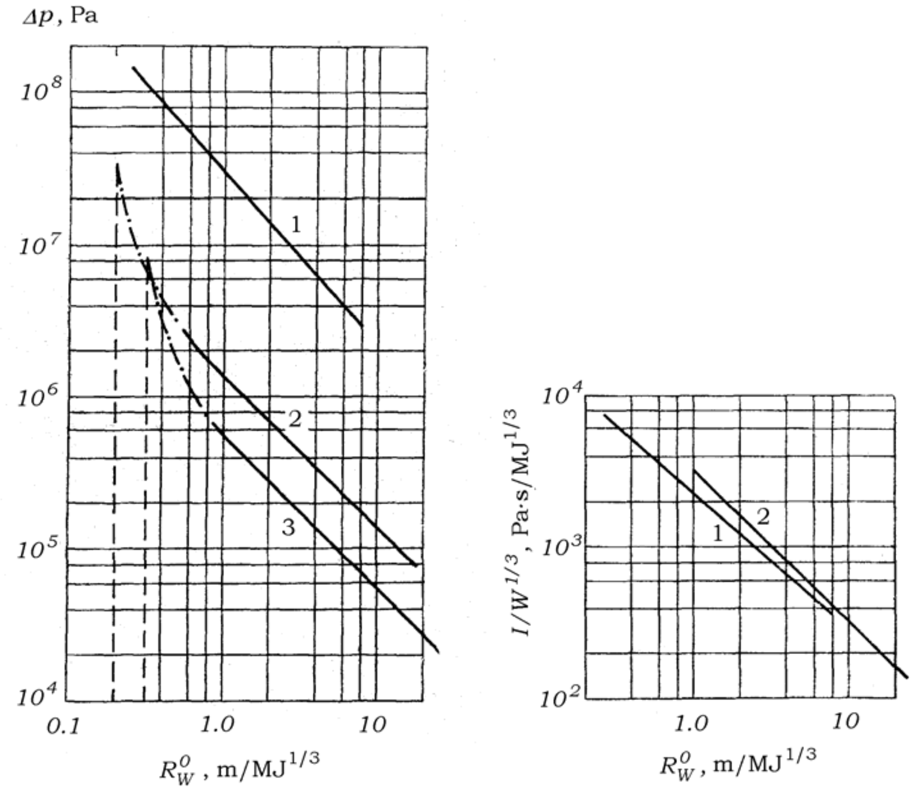

Fig.1 Fig. 2

Fig. 1. Pressure wave amplitudes at different reduced distances: 1 – q = 9.4·10^3 MJ/m^3 (HE); 2 – q = 28.8 MJ/m^3 (gas) ; 3 – q = 7.2 MJ/m^3 (gas).
Fig. 2. Specific impulses from the explosion of TNT (1) and a gas (2)

The dependence of the pressure on the distance in the region $r < (2\text{-}3)R_0$, where the drop in amplitude is different from the acoustic value is superposed by dash-dot lines. The radius of the charge of explosion gaseous mixture under consideration at initial pressure of 10^5 Pa exceeds the radius of the TNT charge by a factor of 9.6.

As follows from Fig. 1, a rise in the volume energy density of the gas mixture will diminish the degree of deviation from energy similarity.
The experimental results [3] for the specific impulse for q=7.2 MJ/m^3 in energy similarity coordinates can be described as

$$I / W^{1/3} = 3.19 \cdot 10^3 / R_W^0 \ .$$

A comparison between the relationships for impulses of gaseous and TNT explosions is given in Fig. 2. It is seen that the specific impulses are close. The wave time constants are compared in Fig. 3.

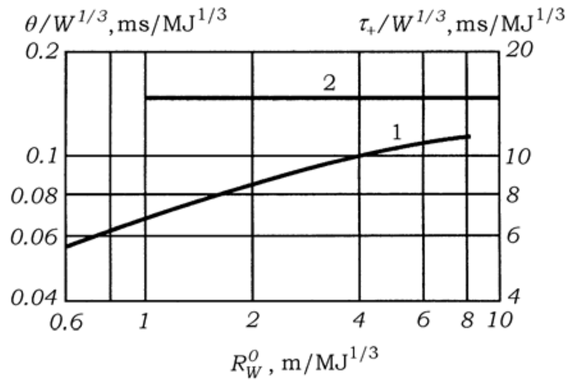

Fig. 3. Comparison between the wave time constants for the explosion of TNT (1) and a gas (2).

4 Pressure-impulse diagram

At low impulse (short duration loads), the response is essentually independent of peak pressure and depends only on the impulse. At low pressures (long duration loads) the response is independent of impulse and depends only on the peak quasi-static load. Using the pressure-impulse diagram the effect of TNT and gaseous detonations on the ichthyofauna can be predicted. Fig. 4 shows that the destructive influence of gaseous explosions on the ichthyofauna occurs only at high initial pressures. The lines 1,2,3 (gas explosions) do not intersect with the lethal border, but the lines 4,5,6 (TNT) do.

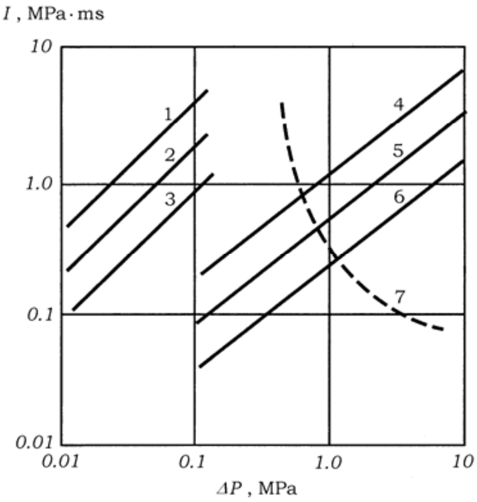

Fig. 4. Pressure-impulse diagram. Gas volumes : 1-58 m^3, 2-5.8 m^3, 3-0.58 m^3 ; TNT : 4-100 kg, 5-10 kg, 6-1 kg ; 7-the border of lethal effect on the sensitive fish fauna [7].

5 Summary

The investigations performed have shown that, as compared to TNT underwater explosions, the behavior of the pressure pulse for the gaseous explosion is different. The amplitude of the pressure wave decreases, whereas the duration of the positive phase of pressure, on the contrary, increases. As a result, the positive impulse for explosions of equal energy is kept constant.

The second distinctive feature of the gaseous explosion is the energy partition. The first pressure wave carries away about 1-2 percent of the energy, about 60 percent of the energy goes with the radial motion of water, and up to 40 percent of the energy remains in the hot products. For reference, a shock wave of TNT explosion carries about 50 percent of the energy, the other 50 percent of energy being consumed by radial motion of water.

A specific feature of gaseous underwater explosions is the nonmonotonic sequence of spikes on the pressure time curve, namely, $p_2 > p_1$. This feature is attributable to the heat losses being intensified by compression of the gas bubble.

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