COMPARISON OF THE ACOUSTIC EFFICIENCY OF SOME SOURCES OF EXPLOSIVE SOUND IN WATER

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Abstract

Full Text

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GEOPHYSICS

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COMPARISON OF THE ACOUSTIC EFFICIENCY OF SOME SOURCES OF EXPLOSIVE SOUND IN WATER

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In marine seismic exploration, the explosion of condensed explosives (HE) is widely used to generate signals employed in studying sections of the sea-bottom strata. Its high acoustic efficiency (up to 59% of the energy goes into the formation of the shock wave) is unattainable for such sources of explosive sound as gaseous HE or a pneumatic radiator (the discharge of compressed air into water). However, for a more precise determination of the range of application of various sources, when considering signal efficiency it is necessary to take into account the distribution of wave energy over different bands of the frequency spectrum.

For condensed HE, the wave parameters have been studied most fully in the zone up to 500 charge radii (^1). However, in this region the study of the spectral composition of the waves for comparison with other sources is not rational because of the strong scattering of energy in the wave. At distances exceeding 500 charge radii, it is possible, to a first approximation, to neglect dissipative losses of energy, since the attenuation of the wave in this zone is explained with a sufficient degree of accuracy only by its geometrical divergence. For TNT at this distance, the wave energy amounts to (^2) 24–21% of that released in the explosion, and the pressures do not exceed 10 kgf/cm^2.

Fig. 1. Distribution of the acoustic energy of an underwater explosion of a TNT charge over different frequency bands: *a* –20-50 Hz, *b* –0-100 Hz, *c* –100-1000 Hz, *d* –1000-10 000 Hz.

For an analytical consideration of the energy frequency spectrum of the shock wave, it is admissible as a first approximation to assume an exponential decrease of pressure behind the wave front,

$$P_t = P_m e^{-t/\theta}. \tag{1}$$

The energy frequency spectrum of the pulse is determined by the expression

$$S_{(\omega)} = P_m^2 \Big/ \left(\frac{1}{\theta^2} + \omega^2\right) \tag{2}$$

and the fraction of energy falling within the frequency interval $(\omega_1 \div \omega_2)$ of the acoustic signal is expressed as the ratio of integrals

$$n = \int_{\omega_1}^{\omega_2} S_{(\omega)}\, d\omega \Big/ \int_0^{\infty} S_{(\omega)}\, d\omega = \frac{2}{\pi}\left(\operatorname{arctg}\theta\omega_2 - \operatorname{arctg}\theta\omega_1\right). \tag{3}$$

Using the empirical dependences [^1] of the time constant θ of the shock wave on the weight of a TNT charge, one can determine the value of n for different charge weights. In Fig. 1, solid lines show the distribution of wave energy over frequency bands as a function of the charge weight at a distance of 1000 charge radii. For each frequency band there is an optimum charge magnitude that gives the maximum energy output. Dashed lines give the results of an experimental determination of the spectral composition of signals for TNT charges weighing 0.044–1.27 kg. Recording was carried out at sea with a barium titanate piezoelectric receiver at distances exceeding 500 charge radii. The amplified signal was recorded with an N-102 loop oscillograph. The recording channel had constant sensitivity in the range 20–3000 Hz and a roll-off not exceeding 20% in the range 3–20 Hz.

According to the experimentally obtained energy frequency spectrum, the ratio (3) was evaluated. The slight deviation of the calculated data from the experimental data (Fig. 1) can be explained by the fact that the exponential decrease of pressure in the shock wave assumed in the calculations is valid only down to a level of 0.3 of the maximum, and thereafter it falls more slowly.

The satisfactory agreement of the calculated and experimental data indicates that the adopted system for recording and processing the results is suitable for estimating the distribution of signal energy in the frequency band 0–1000 Hz and can be used to obtain the material necessary for comparing the efficiency of various sources of explosive sound in water in this frequency range.

Fig. 2. Oscillograms of pressure waves of an underwater explosion:
a –44 g of TNT; *b* –charge of a gas mixture (combustion), 45 kcal; *c* –pneumatic radiator, 35 kcal.

Fig. 2. Oscillograms of pressure waves of an underwater explosion: a –44 g of TNT; b –charge of a gas mixture (combustion), 45 kcal; c –pneumatic radiator, 35 kcal. I –from the explosion; II –from the first collapse of the gas bubble. Frequency of oscillations of the time marker: 500 Hz

Figure 2: Fig. 2. Oscillograms of pressure waves of an underwater explosion: a –44 g of TNT; b –charge of a gas mixture (combustion), 45 kcal; c –pneumatic radiator, 35 kcal. I –from the explosion; II –from the first collapse of the gas bubble. Frequency of oscillations of the time marker: 500 Hz

I –from the explosion; *II* –from the first collapse of the gas bubble. The frequency of oscillations of the time marker is 500 Hz.

For comparison, sources with approximately the same magnitude of released energy were selected.

Gas explosion. Explosions of a stoichiometric mixture of propane-butane with oxygen in a thin-walled rubber shell of spherical shape were used. The mixture was initiated in two ways: by ignition and by explosion of an electric detonator at the center of the charge. In the first case, since the radius of the sphere did not exceed 13-14 cm, according to [^3], combustion does not have time to turn into detonation. In the second case, excitation of detonation is ensured.

Pneumatic radiator. The radiator consisted of a steel chamber of volume 3 l with an outlet opening $d = 65$ mm, opened and closed by a piston. After the chamber was filled with air to a pressure of $120 \div 140$ kgf/cm^2, the piston was set in motion by an electrical signal and, having reached a velocity of 20-30 m/sec, opened the outlet opening. Expansion of the outflowing compressed air leads to the formation in the surroun

···in the surrounding medium. The discharge energy of the pneumatic emitter was determined as the total energy of the adiabatic expansion of the compressed air contained in the chamber.

Figure 2 gives oscillograms of explosions of different sources. The parameters of the excited waves are summarized in Table 1.

Table 1

Type of explosion and released energy	I wave: P_m, kg/cm^2	I wave: I, kg $\cdot$ s/cm$^2 \cdot$ m^2	I wave: E, kcal	I wave: t_{comp}, s $\cdot$ 10^{-3}	I wave: η, %	II wave: P_m, kg/cm^2	II wave: I, kg $\cdot$ s/cm$^2 \cdot$ m^2	II wave: E, kcal	II wave: t_{comp}, s $\cdot$ 10^{-3}	II wave: η, %
TNT 44 g	12.2	11.7	11.5	1.46	24	2.5	22.9	5.9	6.2	13
Gas explosion (ignition) 45 kcal	0.65	17.0	0.88	7.0	1.95	0.6	18.5	1.23	12.1	2.7
Gas explosion (detonation) 39 kcal	0.65	10.8	0.567	5.5	1.45	0.42	12.6	0.52	13.3	1.15
Pneumatic emitter 35 kcal	0.16	13.5	0.295	15	0.85	0.17	26.3	0.625	32.3	1.78

Table 2

Type of emitter and released energy	Full acoustic efficiency, %	Efficiency, %: 0-100 Hz	Efficiency, %: 20-50 Hz	Efficiency, %: 100-1000 Hz
TNT 1.5 g	24	0.302	0.091	2.77
TNT 44 g	24	1.07	0.317	5.94
TNT 255 g	24	1.96	0.595	10.1
TNT 1274 g	24	3.24	1.03	12.8
Gas explosion (ignition) 45 kcal	1.95	1.2	0.415	0.656
Gas explosion (detonation) 39 kcal	1.45	0.7	0.233	0.659
Pneumatic emitter 35 kcal (at different rates of opening of the orifice)	0.75–1.5	0.74–1.47	0.31–0.61	0.03

When a charge of gas mixture was exploded, the first wave was well described by an exponential pulse. With the same amount of gas, the time constant of the exponential when initiated by a detonator was 1.5 times smaller than with ignition. The amplitude of the first wave remained unchanged for different modes of initiation.

A comparison of the parameters of the first wave shows that in passing from condensed high explosive to a gas explosion, the pressure-wave impulse increases slightly, while the maximum pressure and the wave energy decrease by tens of times. The character of the second wave also changes substantially. The duration of its compression phase for all sources is greater than that of the first. The impulse of the second wave for TNT and for the pneumatic emitter increases noticeably in comparison with the first. For a gas explosion it changes only slightly. Under certain process regimes, for a gas explosion and for a pneumatic emitter the efficiency of the second wave may exceed that of the first.

From the oscillograms of the first waves, the energy frequency spectra were calculated and the distribution of acoustic energy over the frequency bands 0–100 Hz, 20–50 Hz, and 100–1000 Hz was determined. The total acoustic ener-

the energy of the wave was determined from the oscillograms by computing the integral

$$E = \frac{4\pi R^2}{S^c} \int_0^{t_{\text{comp}}} P_t^2 \, dt, \tag{4}$$

where P_t is the pressure in the wave; t_{comp} is the duration of the compression phase; R is the distance explosion–piezoelectric receiver; S^c is the acoustic stiffness of water.

The results of these calculations for the first pressure wave are given in Table 2.

The data of Table 2 show that in the frequency range 0–100 Hz the efficiency of a gas explosion and of a pneumatic radiator may, under certain process regimes, exceed the efficiency of a TNT explosion. This conclusion does not apply to charges equivalent, in released energy, to TNT charges of more than 250 g, since for them the efficiency in the 0–100 Hz band exceeds the total efficiency of the gas explosion and of the pneumatic radiator. It is not excluded that the efficiency of the pneumatic radiator can be increased, for example, by raising the pressure in the chamber and increasing the area of the outlet opening while keeping the chamber volume constant.

In the frequency range 100–1000 Hz, the gas explosion and the pneumatic radiator are markedly inferior in efficiency to condensed HE.

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Note: Figure translations are in progress. See original paper for figures.

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