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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

HYDROMECHANICS

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INVESTIGATION OF THE SMOOTHNESS OF A DETONATION FRONT IN A LIQUID EX- PLOSIVE

In recent years, the instability of the one-dimensional regime ⁽⁵⁾ of a detonation wave has been considered theoretically ⁽¹⁻³⁾ and revealed experimentally (in gases ⁽⁴⁾). The surface of the front is not smooth because of the presence of local centers of chemical reaction. In some transparent liquid explosives (l.e.) the microstructure of the detonation wave has been detected ^(6,7) by photographing its own luminosity.

By recording the reflection of light from the front of a shock wave in a liquid explosive, one can directly study the degree of its smoothness, just as was done for a shock wave in inert liquids ⁽⁸⁾.

The resolving power of the method makes it possible to establish the presence of inhomogeneities as small as $5 \cdot 10^{-4}$ cm, which can hardly be achieved by other methods. The assumption of inhomogeneities of smaller size on the detonation front is unrealistic. If individual portions of the surface are inclined from the plane by an angle α , then, when observed from a distance $L \gg l$ (l is the distance from the light source S to the reflecting surface), the blurring of the image will be $2\alpha l$, which under the specific experimental conditions ($l \sim 50$ mm) makes it possible to detect $\alpha \geq 0.01$ radian. Collision of waves with smaller angles of inclination cannot cause a noticeable increase in temperature and pressure and therefore is not characteristic of spin or nonuniform pulsating detonation.

Fig. 1. 1 –SFR objective; 2 –explosive charge with a lens for producing a plane detonation wave; 3 –aluminum cuvette; 4 –prism made of Plexiglas, $n_D = 1.47-1.48$; 5 –vessel with argon; 6 –explosive charge.

Thus, the specular character of the reflection of light from the detonation front should be an unambiguous criterion for the absence of spin or nonuniform pulsating detonation regimes.

Fig. 2a

Figure 2: Fig. 2a

Fig. 2b

Figure 3: Fig. 2b

Experimentally, a transparent liquid explosive mixture of concentrated nitric acid $\rho_4^{20} = 1.523 \text{ g/cm}^3$ and dichloroethane $\rho_4^{20} = 1.257$ was studied. The stoichiometric composition (60/40 parts by weight), in its explosive properties, resembles pressed TNT ($\rho_0 = 1.40 \text{ g/cm}^3$) ($D = 6.2 \pm 0.1 \text{ km/sec}$, $\rho_0 = 1.40 \pm 0.01 \text{ g/cm}^3$). The experimental arrangement (Fig. 1) is the same as in (8). The mixture poured into the cuvette is in contact with glass having a refractive index $n_D = 1.755$, appreciably different from the refractive index of the liquid explosive ($n_D = 1.42$). Light entering the cuvette through the slit S is reflected both from stationary (Fig. 2a, rays I, II, III) and from moving (detonation front, shock waves in inert transparent media) optical boundaries, and through the second face of the prism emerges in the direction of the objective of the photochronograph.

Initiation of the mixture was carried out by an additional explosive charge 220 mm long and 120 mm in diameter of various composition (pressed TNT $\rho_0 = 1.40 \text{ g/cm}^3$, cast TNT $\rho_0 = 1.59 \text{ g/cm}^3$, an alloy of TNT and hexo-

TT 50/50, $\rho_0 = 1.67 \text{ g/cm}^3$). Most of the experiments were carried out in the overdriving regime (initiation by TT 50/50, $u_{\text{piston}} \simeq 2.1 \text{ km/s}$; $u_{\text{zhugge}} = 1.6 \div 1.65 \text{ km/s}$). Overdriving apparently does not affect the character of the detonation (spin or normal), since the state at the chemical peak changes little in this case (the increase in detonation velocity under overdriving lies within the accuracy of its measurement, $\sim 100 \text{ m/s}$). Figure 2b shows a streak photograph on which a distinct specular reflection from the detonation front was recorded (mixture composition 60/40, initial temperature -2° , initiating charge TT 50/50, measured detonation velocity $6.2 \pm 0.1 \text{ km/s}$ and reflection coefficient $R = 1.8 \pm 0.1\%$).

By a photometric method one can determine the absolute magnitude of the reflectivity of the detonation-wave front, taking into account the partial opacity of the mixture. In this case the reflection II in Fig. 2 from the stationary boundary of the liquid explosive with lead glass is used as a reference, since their refractive indices are known.

Fig. 2. I, II, III —reflection of light from the optical boundaries toluene (1)/lead glass (2), lead glass/liquid explosive (3), and from the bottom of the aluminum cuvette (4), respectively. Correspondingly: 5—reflection of light from the detonation front; 6—intrinsic luminescence of the detonation front; 7—reflection of light from a shock wave in TF-5 glass; 8—reflection of light from a shock wave propagating successively in toluene and Plexiglas (the optical bound-

Fig. 3. Streak photograph of the propagation of detonation (mixture of 60% nitric acid with 40% dichloroethane) through a glass tube 60 mm in diameter and 400 mm long, emerging into a wide vessel 100 mm in diameter

Figure 4: Fig. 3. Streak photograph of the propagation of detonation (mixture of 60% nitric acid with 40% dichloroethane) through a glass tube 60 mm in diameter and 400 mm long, emerging into a wide vessel 100 mm in diameter

ary toluene/Plexiglas, with relative refractive index ~ 1 , practically does not reflect); 9—reflection of light from the moving toluene/lead-glass boundary.

Determined in a large series of experiments (analogous to that described, see Fig. 2b), the reflection coefficient proved to be $1.5 \pm 0.4\%$. It is interesting to compare this value with the expected reflectivity of the shock-wave front (chemical peak). For an estimate, the dynamic adiabat of the compressed, unreacted mixture was calculated from the adiabats of the components under the assumption of volume additivity. The density ρ in the wave front was found from the experimental velocity D of the detonation wave and, for $D = 6.2$ km/s, $\rho = 2.5$ g/cm³ (for comparison we note that $\rho_{\text{zhugge}} = 1.9$ g/cm³).

Measurements of the reflectivity of the shock-wave front in dichloroethane and in nitric acid, carried out analogously to ⁽⁸⁾, gave values close to those determined from the relation $(n - 1)/\rho = \text{const}$, where n is the refractive index of the substance under study at density ρ (g/cm³). The refractive index of the compressed mixture was found under this assumption.

The reflection coefficient R , calculated from this value of n and the known refractive index ahead of the front, turned out to be $\sim 1.9\%$ *. We note that the calculated value of the reflection coefficient for a wave with the density at the front equal to the density at the Jouguet point is 0.4–0.5%.

Thus, for the stoichiometric composition and with powerful initiation, there is reasonable agreement between the experimental results and the picture of normal detonation: the reflection is specular, sharply defined, and the reflection coefficient is close to the estimate.

A decrease in the initial temperature of the stoichiometric mixture to -30° , departure from stoichiometry to compositions 30/70 or 80/20, and transition to overdriven detonation (with weakening of the initiating wave) lead to a decrease in reflectivity to values $\lesssim 1\%$. This value does not correspond to the estimated reflection-coefficient values $\geq 1.6\%$, found from the observed wave velocities. This result remained unexplained. However, in all the cases listed, the character of the reflection remains specular.

Fig. 3. Streak photograph of the propagation of detonation (mixture of 60% nitric acid with 40% dichloroethane) through a glass tube 60 mm in diameter and 400 mm long, emerging into a wide vessel 100 mm in diameter

Our results are at variance with the conclusions of ⁽⁹⁾. In nitromethane, in ⁽⁷⁾, an inhomogeneity of the front luminosity and the presence of waves of absence of reaction ⁽⁶⁾ were found. The connection between these phenomena is explained in ⁽¹⁰⁾. In work ⁽⁹⁾, the authors found waves of absence of reaction in mixtures of dichloroethane and nitric acid and, by analogy (see ⁽¹⁰⁾), concluded that the front was inhomogeneous. It was noted above that in our experiments the reflection of light indicates smoothness of the front in mixtures of dichloroethane and nitric acid. In this case (see Fig. 3), in contrast to ⁽⁹⁾, we did not observe waves of absence of reaction.

The principal conclusion of our work is the finding of normal detonation with a plane shock wave ahead of the reaction front in a stoichiometric mixture of dichloroethane and nitric acid.

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* The approximate nature of this value is determined by the assumptions adopted and by the inaccuracy of the initial adiabats of the components.

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

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