Central European Journal of Energetic Materials, **2009**, *6*(1), 7-14.
ISSN 1733-7178

Detonation Parameters of Nitromethane/Methanol Mixtures

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Abstract: Electromagnetic method of registration of partical velocity profile U(t) has been used for investigation of nitromethane/methanol mixtures of different concentration including mixtures in which weigh ratio is close to the detonation limits concentration. In all mixtures in the experimental records of U(t) a typical spike was registered, this enables to locate the Chapman-Jouguet state, and to determine a set of detonation parameters including the pressure $P_{C\text{-}J}$ data which are necessary for finding of true detonation limits on concentration according to methods proposed by Dremin recently. Attention was given to some disagreements with one-dimensional ZND detonation theory.

Keywords: liquid explosives, concentration limits, electromagnetic method

Introduction

It is known that liquid explosive dilution with inert (non-explosive) liquid results in reduction of detonation velocity (parameters) and finally the mixture is not able to detonate at real conditions. This situation is quite predictable from the energetic point of view – the more diluent concentration, the less chemical energy reserve. At some concentration of diluent the energy will be not sufficient for providing self-sustaining regime of detonation process. So that the detonation

limit on concentration (DLC) is coming. But the only energetic approach cannot explain the mechanism of limit without taking into account all detonation transformation mechanism features of the liquid explosives. According to A.N. Dremin's conception, the phenomenon of breakdown of energy-release chemical reaction (thermal explosion) by rarefaction waves underlies all known detonation limits of liquid (homogeneous) energy-containing materials such as initiation and propagation limits, instability of the detonation front, and concentration limit. The possibility of the reaction breakdown is due to strong dependence of heat-release rate by temperature, thus in the case of shock wave processes – by shock pressure and it's reduction under rarefaction waves. It means the nature of all the above limits is kinetics one. The energetic factor can evidently influence the quantitative characteristics of appropriate DLC (for example, the value of detonation failure diameter, the dimension of front inhomogeneity, the correlation of components close to DLC). The instability (non-smoothness) of the detonation front can be considered to be one of the manifestations of Arrehenius' exponent dependence of heat-release rate by temperature. This instability is most distinctly revealed under liquid explosive dilution. The instability was investigated for the first time by Dremin et al. [1, 2] in nitromethane-acetone mixtures using slit photoregistration method. The phenomenon was registered in the form of alternate and intersecting light and dark stripes (pulsating front). As an important result of investigations it is needed to consider the facts of obvious influence on dimensions, character and behavior of pulsations (pulsations appearance and disappearance) by not only the diluent concentration but also the material and dimensions of charge confinement. Apart from practice significance, the similar investigations increasingly arouse scientific interest concerning the possibility to extend the actual conception about detonation as a unique phenomenon.

In the present work nitromethane (NM)/methanol (M) mixtures of different concentration including mixtures in which weigh ratio is close to the DLC using electromagnetic method have been investigated. In the recently published work [3] A.N. Dremin advanced his view that the value of the true DLC can't be determined by available methods. The same limit corresponds to concentration of inert diluent above which the mixture becomes undetonable in principle in spite of the most favorable conditions for process propagation. The method for determination of the true DLC is also suggested and founded. According to [3] the liquid explosives mixture DLC can be found as the crossing point of dependences on diluent concentration both detonation pressure $P_{C\text{-}J}$ and critical shock initiation pressure $P_{cr.}$ In other words, the coming in true DLC will be determined with condition $P_{C\text{-}J} = P_{cr.}$ One of the aims of the work was to get detonation parameters, first of all $P_{C\text{-}J}$. It is necessary to define then the true

detonation limit concentration by use of Dremin's method.

It is significant that the problem of determination as far as possible complete set of detonation parameters for condensed matter cannot be consideral to be solved. From this point of view the use of electromagnetic method in present investigation is the most reasonable.

Methods and experiment conditions

The electromagnetic method of registration of particle velocity profiles U(t) of shock and detonation waves has been widely and effectively used especially for the solid explosives which may have different initial structure and degree of heterogeneity of charges (cast, pressed and poured). On the U(t) oscillograms of detonation waves profile, a typical spike is registered. The same spike is identified with von Neumann spike predicted by hydrodynamic Zel'dovich-Neumann-Doering (ZND) theory of detonation. The registration of the spike in electromagnetic measurements in charges of different structures was considered as a proof of validity and, to a certain degree, of universality of ZND theory with respect to structure and state of explosive [4]. In this case, according to the theory, the inflection point on the oscillogram of U(t) is the Chapman-Jouguet state, that enables to determine the values of the particle velocity of detonation products $U_{C\text{-}J}$ and the duration of chemical reaction $t_{C\text{-}J}$ in detonation front. The determination of particle velocities and measurement of detonation velocity D (using stepped gage) allowed to calculate the pressure of detonation products utilizing the formula of momentum conservation law $P_{C\text{-}J} = \rho_0 D\, U_{C\text{-}J}$. However, in comparison with solid explosives, a number of works in which the electromagnetic method was purposefully used for appropriate investigations in liquid explosives is not great. Until recently the experimental data on detonation parameters of many practically interesting liquid explosives, in essence, consisted of data on detonation velocity D as a parameter which is easy measured in experiment. This situation may be explained from different points of view. Let us call attention to two main factors which determine the difference in behavior of solid and liquid explosives under shock wave loading: initial homogeneity (physical uniformity) of liquid matter and its strong (Arrehenius' exponent) dependence of chemical heat release rate by temperature. This factors cause anxiety that the interaction between detonation front and a gage metal surface (any foreign matter) is able to influence energy-release process and cause the distortion of U(t) oscillograms from the point of view of their correspondence to the true detonation wave profile.

According to [5] the same effects could be minimized by the appropriate choice of the gage thickness. In present work the gages from aluminum foil with different thickness: 120 (usually used in solid explosives charges), 50, 30, 20, and 10 microns were used. During experiments it was found that the most reliable data are obtained when the gages of 30-50 microns thick are applied. Experimental assembly scheme is shown in Figure 1. The stainless (non-magnetic) steel confinements (56 mm in outer diameter, 3 mm thick) were mainly used. Reliable initiation (with small overdriven) was executed by the TNT charge of 60 mm diameter through the 6 mm thick plexiglass layer. The gages with work surface 10×10 mm^2 were placed within 120-130 mm from plexiglass, the base of velocity D measurement was 20-25 mm. One can not be noticing the use of metal confinements in electromagnetic method is undesirable. In present investigations the utilization of metal confinements was caused by the necessity to detonate as small as possible quantity of explosive between the poles of stationary electromagnetic installation. Steel confinements with moderate diameter of 50 mm provided stable (without failure) propagation of the detonation process in all mixtures under study.

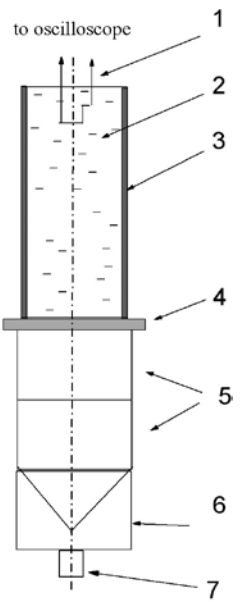

Figure 1. Experimental assembly scheme: 1 – stepped electromagnetic gage; 2 – liquid under study; 3 – confinement; 4 – plexiglass layer; 5 – explosive (pressed TNT); 6 – explosive lens; 7 – tablet for electric detonator.

To understand and to take into account an influence of any stray pick-ups on the measurement results, the check experiments with the least diluted mixture were carried out. In particular, oscilloscope beam deflection from zero level before the main signal was observed, such situation introduced an uncertainty in the estimation of signal amplitude which determined the value of appropriate particle velocity. The experiments with glass confinements make possible solution of this problem.

Nitromethane and methanol with densities of 1.136 g/cm^3 and 0.793 g/cm^3, with refraction indexes of 1.3816 and 1.3288 respectively, were utilized in this investigation. Detonation velocity measured for nitromethane has been found 6.27 ± 0.02 km/s. The temperature of mixtures during experiments was in range of 18-22 °C.

Results and Discussion

The specific spike in oscillograms of U(t), which is typical for detonation wave profile, was recorded for all investigated mixtures (Figure 2). The spike registered permits to determine a sufficient set of detonation parameters. The composition of liquid mixtures and finding of determination of their detonation characteristics are presented in Table 1.

Table 1. Detonation parameters of NM/M mixtures

Composition, NM/M	**ρ_0,** g/cm^3	**D,** km/s	**$U_{C\text{-}J}$,** km/s	**$P_{C\text{-}J}$,** GPa	**$t_{C\text{-}J}$,** μs
90/10	1.088	5.91	1.46	9.4	0.13 – 0.20
80/20	1.044	5.58	1.39	8.1	0.14 – 0.22
75/25	1.024	5.41	1.38	7.6	0.20 – 0.28
70/30	1.005	5.25	1.36	7.2	~ 0.30
65/35	0.985	5.08	1.35	6.8	~ 0.30

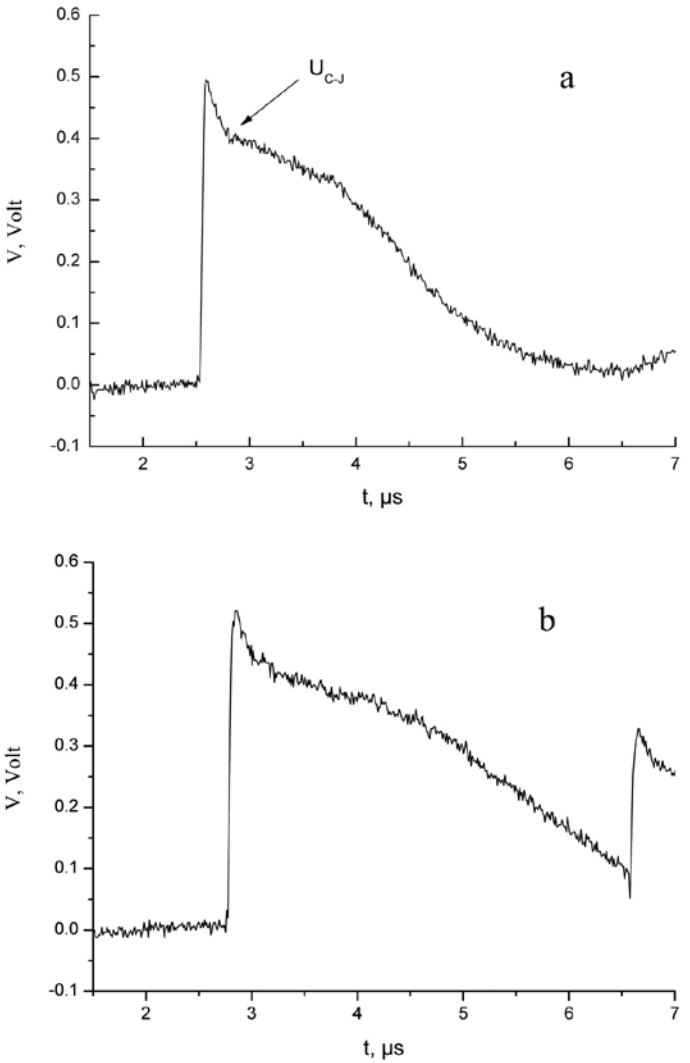

Figure 2. Oscillograms of particle velocity profiles U(t) for 70/30 NM/M mixture: a – gage made of 30 micron thick aluminum foil; b – stepped gage, 50 micron thick.

Detonation velocity values D in the table were taken directly from the dependence D = (6.25-3.39 α) km/s, by which experimental data were fitted. This dependence is presented in Figure 3 together with the values of D obtained in experiments (data for NM/M 62/38 wasn't taken into account in fitting). Dependences of D (α) calculated by the method [6] and also given in [7] dispose

over experimental one. Particularly near the DLC the difference in the velocities amounts to 0.65 km/s. Values of $U_{C\text{-}J}$ as the average of 4-6 measurement, are introduced in the table, their maximum deviations from experimental velocities didn't exceed 1.5%.

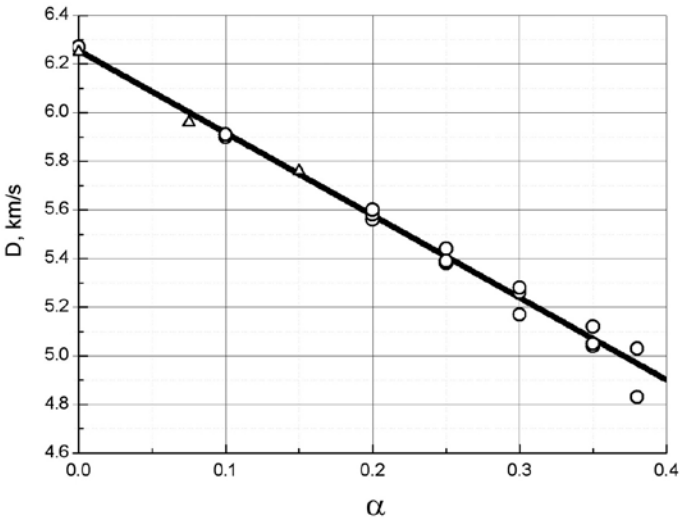

Figure 3. Detonation velocity D for NM/M mixtures with various methanol weight content of α: ○ – present work data; Δ – from Ref. [7].

But special attention should be paid to the following aspect. The values of detonation velocities registered in experiments have been found to be notably larger than the shock wave velocities calculated by the substitution of the particle velocity values taken from the front of U(t) oscillograms to the appropriate mixture's Hugoniots. In this case shock adiabats of mixtures were got in accordance to a generalized shock adiabat for organic liquids $D = 1.2\ C_0 + 1.7\ U$ (C_0 - sound velocity) [8]. This fact does not quite agree with ZND detonation theory. According to the theory a detonation wave's fore-part represents a smooth shock front that is propagating with detonation velocity. Dilution of liquid explosives by non-explosive liquid inevitably results in pulsations at the front, i.e. gives rise to the detonation front to be unstable, non-one-dimensional (non-smooth) [2, 3]. NM/M mixtures under study are not exclusions. It needs to be found out to what extent this circumstance can cause the "discrepancy" between the values of detonation front and particle velocities. Note thereupon, that the question of adaptability of one-dimensional ZND theory to detonation with rough (kinetically unstable) pulsating front (the

rule of selection for velocity and determination of detonation parameters, limits phenomena) was raised and considered by Dremin and Trofimov (for example, [9, 10]), and the question has not lost its significance at the present time.

Acknowledgement

This work was supported by International Science and Technology Center (Project No. 3394). The Project Proposal "On the capability of liquid homogeneous materials to detonate" was presented to ISTC by scientific group led by A.N. Dremin.

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