Exploding wires initiation of nitromethane sensitized by diethylenetriamine

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Abstract. Experiments on initiation of nitromethane sensitized by diethylenetriamine in weight proportion 98/2 by exploding wires were conducted. Several conditions of initiation of low speed detonation were determined.

1. Introduction
The era of liquid high explosives (LHE) began since 1847, when nitroglycerine was presented by A Sobrero [1]. Two-component liquid explosives were suggested by H Sprengel, who patented a variety of mixtures in 1871 [2]. The explosives were made of stoichiometric mixture combustible and oxidizing agents, both components were inexplosive. At least one of the components was a liquid.

The high explosives considerably improved blasting operations. A lot of new compositions of LHE were developed, which were widely used in industrial blasting due to low cost, high safety and simplicity of handling. Detailed description of modern status of detonation physics of LHE is presented in paper [3].

Sometimes condensed high explosives are used as a component of LHE for providing unique properties, but the greatest popularity received mixtures consisting only of inexplosive materials. These mixtures are usually prepared just before blasting, that considerably reduces expenses of transportation, storage and safeguarding of explosive materials. Another significant advantage of LHE is reduction of number of operations with explosive materials to a minimum. Sometimes LHE are alternative candidate for utilization in pulse power devices, employing transformation of chemical energy into electric energy [4, 5].

Unsophisticated initiators without explosive or pyrotechnic compositions were developed for some LHE, that additionally increased safety of blasting [6, 7]. Electrical systems of blasting without conventional detonators were also realized for a number of scientific and technical devices. Exploding wires [8,9] or an electric spark discharge [10] were used in it.

Several initiation conditions of low speed detonation were investigated in this work. A mixture of nitromethane (NM) and diethylenetriamine (DETA) was prepared in a weight ratio of 98/2. The mixture was placed in polyvinylchloride (PVC) tube, and it was initiated by an electric explosion of copper wires.

Pure nitromethane is a flammable liquid usually not sensitive to heat or mechanical impact, it can be detonated by a strong initiator [11]. The critical diameter of unconfined charge of NM is
26.5–27.0 mm [12]. Temperature effects on the detonation parameters of NM in glass tubes were studied in [13]. Chaiken [14] suggested the phenomenological model of formation of a detonation wave in nitromethane at shock-wave initiation. The overtaken wave arises with some induction time behind the front of the initial wave according to his theory. The steady detonation appears after the moment, when the overdriven wave has overtaken the initial wave. Later Dremin [15] refined this model for the description of a detonation of homogeneous LHE. A detonation overtake time falls from 5 \( \mu \text{s} \) to 0.15 \( \mu \text{s} \) in neat NM at increase in shock input pressure from 8 to 12 GPa, the review of the relevant experimental data is given in the paper [16].

It is known that chemical bases are the strong sensitizers of NM, and acids are weak sensitizers of NM [17]. Diethylenetriamine, ethylene diamine and triethylene tetramine are the most efficient sensitizers of NM among amines. This phenomenon has been determined by decrease of critical diameter [18] and gap test measurements [19]. Detonation properties of mixture NM–DETA in glass (Pyrex) tubes were measured in the work [19], the critical diameter changed from 16 mm to 4.7 mm at increase in concentration of a sensitizer from 0 to 2.5\% . The critical diameter of mixture NM–DETA at concentration of DETA up to 2\% was investigated later, the critical diameter of mixture with concentration DETA 2.5\% in polyvinylchloride (Tygon TM) tube was about 3 mm [20].

Shock-wave sensitivity of NM is increased by additions of amines. It was measured [21] that at shock-wave initiation of mixture NM–DETA by pressure 6.1 GPa, the time to detonation is reduced from 18 \( \mu \text{s} \) to less than 1 \( \mu \text{s} \) at increase of DETA concentration from 0 to 5\%. An exploding wire initiation of LHE exhibits a number of peculiarities. First, both the impulse of high pressure, and a thermal impulse from the exploding wires acts on LHE. Secondly, different hydrodynamic effects caused by a time dependence of pressure puls are possible. This method of LHE initiation is the least investigated.

2. Experimental setup
The experimental setup included a high voltage charging device, a discharge circuit, exploding wires and a single-shot plastic vessel filled by the investigated mixture.

The electric scheme used in experiments is shown in figure 1.

The capacitor bank \( C_0 \) was assembled by a parallel connection of the low-inductive pulse capacitors CP 42-10, produced by “Energy” Holding [22]. Each capacitor had 10 \( \mu \text{F} \) rated value, with operational voltage up to 42 kV, insulation resistance 30 M\( \Omega \)hm, and maximum charging current 100 kA. The bank capacitance was varied in the range of 10–150 \( \mu \text{F} \) by changing a number of capacitors switched in the circuit.

The total inductance of the circuit was \( L = 1–2 \mu \text{H} \), it included self-inductance of capacitors, coaxial cables, flanges of output current collectors, and inductance of a discharge gap with exploding wires. The total resistance of the circuit was consisted of the resistance \( R(t) \) of exploding copper wires and resistance \( r \) of the transition line with the coaxial cables. The energy input in the exploding wires was regulated by the charging voltage \( (U_0 = 10–40 \text{kV}) \) and electric capacity \( C_0 \) of the bank.

Electric current was switched on by the triggered vacuum spark gap RBY-43-1 [23]. The spark gap was designed for working voltages 0.5–35 kV and operating current range 5–300 kA. The maximum charge is limited to 200 coulombs. The switch was actuated by 5 kV high voltage pulse, that was applied between basic electrode and igniter electrode.

Output \( dI/dt \) current derivative signals were measured by Rogowski coil, with relative accuracy being better than 10\%. The signals were registered in LeCroy 324 oscilloscope, and they were integrated numerically. A high-voltage attenuator was used to measure the charging voltage \( U_0 \).
Figure 1. Experimental equivalent electric circuit: $C_0$—capacitor bank; $L$—total inductance; $r$—resistance of the transition line; $R(t)$—resistance of exploding wires.

Figure 2. The scheme: 1—liquid high explosive; 2—polyvinylchloride tube; 3—exploding wires; 4—textolite plug; 5—electrodes; 6—witness plate.

Figure 3. The measured derivative (circles) and the modeled derivative (line) as functions of time in experiment 97 with short-circuit electrodes.

Figure 4. The integrated derivative (squares) and the simulated current (line) as functions of time in experiment 97 with short-circuit electrodes.

3. Experimental scheme
The experimental scheme is presented in figure 2. A high voltage charger and triggering devices were placed indoors. The plastic tube with investigated mixture was fixed between electrodes on the open explosive area. LHE mixture was prepared in advance, it was filled in PVC tube with inner diameter 22 mm, wall thickness 1.5 mm and height 100 mm. A textolite plug was used to seal up the bottom end of the tube. Exploding wires were located on the plug surface and were isolated from LHE by a thin lavsan film. A textolite witness-plate was placed under the plug.
Table 1. Experiments with exploding wires in water.

| No. | Parameters of exploding wires | $U_0$, $E_0$, Comments |
|-----|------------------------------|------------------------|
|     | diameter, length, number of pieces | kV, kJ | |
| 49  | 0.12, 25, 288                  | 20.7, 32.1 Broken tube, small fragments |
| 50  | 0.12, 25, 288                  | 20.6, 31.8 Broken tube, small fragments |
| 51  | 0.18, 24, 5                    | 5.1, 1.9 Unbroken tube |
| 53  | 0.1, 25, 240                   | 25.6, 49.5 Broken tube, small fragments |
| 54  | 0.12, 26, 192                  | 20, 30 Broken tube, small fragments |
| 97  | 4, 30, 1                       | 20, 20 Short-circuited electrodes test |

Table 2. Experiments with exploding wires in NM–DETA mixture.

| No. | Parameters of exploding wires | $U_0$, $E_0$, Comments |
|-----|------------------------------|------------------------|
|     | diameter, length, number of pieces | kV, kJ | |
| 25  | 0.18, 24, 10                  | 8.2, 5.0 No detonation |
| 52  | 0.18, 24, 5                   | 5.2, 2.0 No detonation |
| 62  | 0.12, 26, 64                  | 10.9, 8.9 No detonation |
| 63  | 0.12, 26, 128                 | 15.9, 19.0 No detonation |
| 70  | 0.12, 26, 192                 | 22.7, 38.7 Cracks in the witness plate |
| 71  | 0.12, 26, 192                 | 25.7, 49.5 Cracks in the witness plate |
| 100 | 0.12, 30, 64                  | 20, 2.0 No detonation |
| 101 | 0.12, 30, 128                 | 20, 2.0 No detonation |

Electrical parameters of the circuit under consideration provided an oscillatory discharge. The capacitance $C_0$ was measured in static conditions. Values of $r$ and $L$ were calculated according to a time dependences of current derivatives in short-circuited electrodes tests (figures 3 and 4).

4. Results

Influence of hydraulic shock on PVC tube due to electrical explosion was investigated in the first group of experiments. Some experimental data on electrical explosion of copper wires in PVC tubes filled by water are presented in the table 1. Here $U_0$ is the charging voltage, $E_0$ is the initial energy of the charged capacitor bank. The charging voltage was varied within 3–30 kV. The electric explosion did not lead to destruction of the tube at quantity of wires 5–10 pieces. The PVC tube collapsed on small fragments at electrical explosion of a larger number of wires (128–288 pieces). The witness plate and the electrodes remained unbroken at electrical explosion of any number of wires in water. The second group of experiments was carried out with NM–DETA mixture in a weight proportion of 98/2. The mixture was filled in the PVC tube. Certain results of exploding wires initiation of NM–DETA mixture are assembled in the table 2.

The detonation failure was determined by absence of cracks in the witness plate, absence of deformations of electrodes and spilled mixture. Typical oscillograms of experiment without detonation are provided in figure 5, the dependence of integral of specific current action [24] of
copper wires on time are shown in figure 6. The detonation failure was detected in all experiments with small number of exploding wires (less than 100 pieces), for example, experiments 25, 52 and 62 (table 2).

A slow speed detonation regime was initiated by exploding wires with spot about 5–10 mm that was provided by number of wires 192 pieces. Bunch of wires with diameter 0.12 mm was used, capacity of the bank was 150 \( \mu \)F. Charging voltages of the capacitors varied from 15 to 30 kV. The total inductance of the circuit was about 1.4 \( \mu \)H. The regime was determined by existence of cracks and prints in the witness plate, with electrodes being deformed. The oscillogram of experiment 70 is shown in figure 7, the calculated integral of specific current action is presented in the figure 8.
5. Conclusions
Experiments on initiation of NM–DETA mixtures by electrical explosion of Cu wires have been conducted. Three main modes have been registered: a low speed detonation, combustion of the mixtures, a failure of combustion/detonation with destruction of the vessel. A combustion of the mixtures as well as hydrodynamic destruction of the polyvinylchloride thin-walled tube should be realized at the total cross-sectional areas of unexploded wires less than 2.2 mm$^2$. The low speed detonation should be initiated at the total cross-sectional areas of the wires more than 2.2 mm$^2$.

References
[1] Sobrero A 1847 C. R. Hebd. Seances Acad. Sci. 24 247–8
[2] Sprengel H 1873 J. Chem. Soc. 26 796–808
[3] Dremin A N 1995 J. Phys. IV 5(C4) 259–76
[4] Mintsev V B, Ushnurtsev A E, Fortov V E, Leontyev A A, Shurupov A V and Kiuttu G F 2001 Multi-stage flux-trapping helical flux compression generators The 28th IEEE Int. Conf. on Plasma Science and 13th IEEE International Pulsed Power Conf., Book of Proc. ed Reinovsky R and Newton M (Las Vegas) p 994
[5] Fortov V E et al 2010 Magnetocumulative generator as the power supply for pulsed plasma accelerator The Thirteenth Int. Conf. Megagauss Magnetic Field Generation and Related Topics (MG-XIII), Book of Proc. ed Sun Chengwei et al (Suzhou, China) p 986
[6] Reithel R J 1964 Low voltage detonator system patent USA 3158098
[7] Dobrynin A A and Dobrynin I A 2012 Safe device for electric initiation of fluid explosives patent RU 2471144
[8] Belyaev A F 1938 Dokl. Akad. Nauk SSSR 18 267–70
[9] Pinaev A V and Kochetkov I I 2012 Combust., Explos. Shock Waves 48 367–73
[10] Zotov E V 1996 Combust., Explos. Shock Waves 32 114–20
[11] McKittrick D S, Irvine R J and Bergensteen I 1938 Ind. Eng. Chem., Anal. Ed. 10 630–1
[12] Nahmani G and Manheier Y 1956 J. Chem. Phys. 24 1074–7
[13] Campbell A W, Malin M E and Holland T E 1956 J. Appl. Phys. 27 963
[14] Chaiken R F 1960 J. Chem. Phys. 33 760–1
[15] Dremin A N, Savrov S D, Trofimov V S and Shvedov K K 1970 Detonation Waves in Condensed Medium (Moscow: Nauka)
[16] Dattelbaum D M, Sheffield S A, Stahl D B and Dattelbaum A M Low voltage detonator system Los Alamos National Laboratory Report LA–UR–09–07755
[17] Urbanski T 1964 Chemistry and Technology of Explosives vol 1 (Oxford–London–New York–Paris: Pergamon Press)
[18] Kondrikov B N, Kozak G D, Raikova V M and Starshinov A V 1977 Dokl. Akad. Nauk SSSR 233 402–5
[19] Engelke R 1980 Phys. Fluids 23 875–80
[20] Lee J J, Jiang J, Choong K H and Lee J H S 2000 AIP Conf. Proc. 505 797–800
[21] Walker F E 1979 Acta Astronaut. 6 807–13
[22] URL http://holding-energy.ru
[23] Sidorov V A and Allerov D F 2001 Instrum. Exp. Tech. 44 72–80
[24] Knoephel H 1970 Pulsed High Magnetic Fields (Amsterdam, London: North–Holland Publishing Company)