ON THE MECHANISM AND SPECIFIC FEATURES OF INITIATION OF THE EXPLOSION OF A PRESSED MIXTURE OF AMMONIUM PERCHLORATE AND SEVILENE WITH ALUMINUM ADDITIVE BY A HIGH-VOLTAGE DISCHARGE

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Abstract: In the previous works of the authors, it was shown that a stoichiometric mixture of ammonium perchlorate and sevilene (thermoplastic adhesive, copolymer of ethylene and vinyl acetate) with the addition of 20% of micron-sized aluminum powder in pressed dense samples produces an explosion when initiated by an electric high-voltage discharge. The minimum discharge energy at which an explosion is excited at a discharge gap length of 5 mm was only 0.6 mJ. In this work, new experimental data were obtained that made it possible to estimate the completeness of the explosion in combustion chambers of different diameters and with different electrode locations as well as to determine the critical diameter at which the explosive process after initiation spreads without attenuation along an elongated sample. New data on the explosion mechanism were obtained using a limiting resistance which was introduced into the electric circuit of the high-voltage generator in series with the fuel sample. With a resistance of 10 to 50 MOhm, the discharge still resulted in an explosion but the voltage drop of the capacitor bank measured before and after the explosion was insignificant. The electrical energy consumption for the explosion was only a few joules compared to 280 J in the absence of a limiting resistance under the same conditions. Thus, the overwhelming majority of the electrical energy of the discharge during an explosion is consumed not on initiation but on heating the plasma of the combustion products after initiation. With a resistance of 100 MOhm, the electrical discharge did not result in an explosion. Under these conditions, volt-ampere measurements were performed which showed that the resistance of the fuel sample changes significantly as the voltage increases or decreases demonstrating a section of behavior similar to a dielectric (voltage range from 0.1 to 1.5 kV), a section of ionization or avalanche-like breakdown (range from 1.5 to 1.6 kV) when the resistance of the sample decreases by almost two orders of magnitude at an unstable discharge current, and a section of monotonic decrease in resistance by more than an order of magnitude (range from 1.6 to 10 kV) at a stable discharge current.

Keywords: explosion; high-voltage electric discharge; mixed explosive materials; ammonium perchlorate; sevilene; powdered aluminum; volt-ampere characteristic; electrical resistance

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Figure Captions

Figure 1 Testing fuel charges with electrodes of different configurations: (*a*) variant A — parallel placement of electrodes; (*b*) variant B — coaxial placement of electrodes; *1* — negative electrode; *2* — piston made of fluoroplastic or caprolon; *3* — paper-bakelite tube; *4* — charge from the fuel mixture; *5* — steel bolt with nut; *6* — steel washer; *7* — fluoroplastic table; and *8* — positive electrode

Figure 2 Combustion chambers for studying the explosive properties of a compressed mixture: (*a*)–(*d*) options A–D; *1* — engine body; *2* — fuel pellet; *3* — insulating caprolon cylinder with electrode; *4* — negative electrode (steel tube afterburning chamber in variants A and B); *5* — cylinder-insulator (tube made of cambric in variant A and insert made of caprolon in variant D); *6* — auxiliary electrode; *7* — nozzle; *8* — split surface of caprolon body; *9* — hole for guide rod of stand; *10* — unburned fuel residue; D — nozzle diameter; D_1 and D_2 — diameters of large and small channels in experiment to determine critical detonation diameter (variant C); and L — total length of nozzle together with afterburning chamber. Dimensions are in millimeters

Figure 3 Test bench for determining the efficiency of fuel explosion in pulse engines: *1* — platform for fixing the guide rods; *2* — guide rod; *3* — polypropylene tube that provides sliding along the guide rod; *4* — load-aluminum cylinder; *5* — connecting pins; *6* — fluoroplastic platform; *7* — corner that provides fastening of the platform to the paper-bakelite tube; *8* — paper-bakelite tube; *9* — steel cup; *10* — pulse engine; *11* — negative electrode; *12* — fuel checker; and *13* — cardboard ring — indicator of the lifting height of the load with the engine. Dimensions are in millimeters

Figure 4 High voltage direct current generator: TR — F.A.R.T. transformer; D — high-voltage diodes; C — capacitor bank; V — digital kilo-voltmeter; KP — discharge button; $R_{\rm o}$ — limiting supply resistance; and R_x — discharge limiting resistance

Figure 5 Dependence of the sample resistance R on the applied voltage U_{o} for $R_x = 100$ MOм: (*a*) in the area from 0 to 2 kV; and (*b*) in the area from 1.6 to 2 kV

Figure 6 Dependence of the voltage drop across the sample U_r on the applied voltage U_{o}

Table Captions

Table 1 Test results of the fuel composition at the stand: D — diameter of the combustion chamber; m — mass of the fuel; M — mass of the thrown load with the engine; L — length of the nozzle (together with the afterburner chamber in experiments 3–5); R_x — limiting discharge resistance; U_{o} — voltage on the capacitor bank before the explosion; U_k — voltage on the capacitor bank after the explosion; H — lifting height the thrown load with the engine; Y_e — calculated specific impulse of product's ejected; and Q — completeness of fuel combustion

Table 2 Values of characteristics on the graphs of Figs. 5 and 6

References

1. Sadovnichii, D. N., Yu. M. Milekhin, S. A. Lopatkin, V. F. Vazhov, S. A. Gusev, and E. A. Butenko. 2010. Pulsed electrical breakdown of energetic composite condensed systems. *Combust. Explo. Shock Waves* 46(4):464–471.
2. Bragin, V. A., S. A. Dushenok, V. G. Kulikov, G. G. Savenkov, and G. V. Semashkin. 2012. Influence of metal nanopowders on the sensitivity of explosives to a high-voltage electric discharge. A fractal-percolation approach. *Russ. J. Phys. Chem. B* 6(3):390–396.
3. Khaneft, I. G., and A. V. Khaneft. 2013. Elektricheskiy proboy polikristallicheskikh tabletok perkhlorata ammoniya [The electric breakdown of polycrystalline ammonium perchlorate tablets]. *Khimicheskaya fizika i mezoskopiya* [Chemical Physics and Mesoscopy] 15(1):37.
4. Rashkovskii, S. A., and G. G. Savenkov. 2013. Initiation of detonation by a high-voltage discharge in powdered explosives with nanosize inert admixtures. *Tech. Phys.* 58(4):511–522.
5. Sadovnichii, D. N., Yu. M. Milekhin, S. A. Lopatkin, T. S. Skripina, S. A. Malinin, and I. N. Gross. 2019. Dielecric relaxation in energy condensed systems on the basis of polyefirretane elastomer. II. Temperature dependence and ignition. *Combust. Explo. Shock Waves* 55(2):220–229.
6. Rebeko, A. G., and B. S. Ermolaev. 2021. Initsiirovanie vzryva vysokovoltnym razryadom pressovannykh smesey sevilena s perkhloratom i nitratom ammoniya s dobavkoy poroshkoobraznogo alyuminiya [Initiation of explosion by high voltage discharge of pressed mixtures of sevilene with ammonium perchlorate and nitrate with addition of powdered aluminum]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 14(3):122–129.
7. Rebeko, A. G., and B. S. Ermolaev. 2022. Vzryvchatye svoystva pressovannykh sostavov na osnove perkhlorata ammoniya i sevilena s dobavkoy alyuminiya. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 15(3):108–116.
8. Svetlov, B. Ya., and N. E. Yaremenko. 1973. *Teoriya i svoystva promyshlennykh vzryvchatykh veshchestv* [Theory and properties of industrial explosives]. Moscow: Nedra. P. 42.
9. Ermolaev, B., and A. Sulimov. 2019. *Convective burning and low-velocity detonation in porous media*. DEStech Publications. 335 p.
10. Ermolaev, B. S., A. A. Belyaev, A. V. Roman'kov, V. E. Khrapovskii, A. A. Sulimov, and A. G. Rebeko. 2019. Behavior of low-velocity detonation in stoichiometric mixture of ammonium perchlorate and polyamethyl methacrylate. *Russ. J. Phys. Chem. B* 13(4):646–656.
11. Horowitz, P., and W. Hill. 1989. *The art of electronics*. 2nd ed. Cambridge University Press. 1044 p.
12. Rokhlin, G. N. 1991. *Razryadnye istochniki sveta* [Discharge light sources]. Moscow: Energoatomizdat. 720 p.
13. Rayzer, Yu. P. 1992. *Fizika gazovogo razryada* [Physics of gas discharge]. Moscow: Nauka. 536 p.

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