ENERGY CHARACTERISTICS AND FEATURES OF LASER INITIATION OF PYROTECHNIC MIXTURE OF POTASSIUM PERCHLORATE WITH RED BLOOD SALT

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Abstract: A pyrotechnic mixture of potassium perchlorate and potassium hexacyanoferrate (III) was obtained and studied and the composition of the mixture and the dispersion of its components were determined. The heat of combustion of this mixture was determined as well as its sensitivity to impact and electric spark. The mixture exhibits sensitivity to shock and electrical discharge at a level of lead styphnate. Experimental studies of the process of its ignition by laser radiation of 405 and 450 nm with a duration of 0.5 to 1000 ms were carried out. The duration of the ignition pulse and the time delay of initiation were determined and the minimum ignition energy was estimated depending on the radiation intensity in the range from 20 to 1600 W/cm^2. A noticeable decrease in ignition energy was found compared to infrared radiation which is explained by the photochemical exothermic decomposition of red blood salt.

Keywords: mixture of potassium perchlorate – red blood salt; energy characteristics; laser initiation

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Figure Captions

Figure 1 Photographs of the potassium perchlorate (PP) / potassium hexacyanoferrate (III) (PH) mixture on electron microscope

Figure 2 Absorption spectra of PH solutions at various concentrations: *1* — 0.01 g/100 ml No. 1; *2* — 0.01 No. 2; *3* — 0,01 (+ PP) No. 3; *4* — 0.02; *5* — 0.03; and *6* — 0.005 g/100 ml

Figure 3 Graduation line $A = 1025.175038C$

Figure 4 Differential scanning calorimetry of PH in nitrogen

Figure 5 Differential scanning calorimetry of PP/PH – cellulose triacetate 4% in air

Figure 6 Oscillogram of PP/PH ignition by a 405-nanometer laser pulse when searching for t_m: *1* — laser power supply; and *2* — photosensor signal

Figure 7 Dependence $t_m = f(P/S)$ for PP/PH for lasers 405 (*1*) and 450 nm (*2*)

Figure 8 Enlarged views of laser spots during ignition failure

Table Captions

Table 1 Sensitivity of PP/PH mixture to impact on a K-44-1 pile driver

Table 2 Combustion characteristics for PP/PH mixture

Table 3 Values of Q_{psi} and E/S for porous PP/PH sample

References

1. Burkina, R. S., E. Yu. Morozova, and V. P. Tsipilev. 2011. Initiation of a reactive material by a radiation beam absorbed by optical heterogeneities of the material. *Combust. Explo. Shock Waves* 47:581–590.
2. Kalenskii, A. V., N. V. Gazenaur, A. A. Zvekov, and A. P. Nikitin. 2017. Critical conditions of reaction initiation in the PETN during laser heating of light-absorbing nanoparticles. *Combust. Explo. Shock Waves* 53(2):219-228. doi: 10.1134/S0010508217020137.
3. Tarzhanov, V. I., V. I. Sdobnov, A. D. Zinchenko, and A. I. Pogrebov. 2017. Laser initiation of low-density mixtures of PETN with metal additives. *Combust. Explo. Shock Waves* 53:229–235.
4. Szimhardt N., M. H. H. Wurzenberger, L. Zeisel, M. S. Gruhne, M. Lommel, T. M. Klapotke, and J. Stierstorfer. 2019. 1-Aminotriazole transition-metal complexes as laser-ignitable and lead-free primary explosives. *Chem. — Eur. J.* 25(8):1963–1974. doi: 10.1002/chem.201803372.

5. Alibaev, A. F., I. G. Assovsky, D. B. Dmitrienko, G. P. Kuznetsov, and G. V. Melik-Gaykazov. 2021. Opredelenie vremeni zaderzhki vzryva pri lazernom iniysiirovanii energoemkikh soedineniy [Determination of the explosion delay time during laser initiation of energy-intensive compounds]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 14(1):77–82. doi: 10.30826/CE21140109.
6. Assovskiy, I. G., D. B. Dmitrienko, G. P. Kuznetsov, G. V. Melik-Gaikazov, and V. P. Sinditskii. 2022. Lazernoe initsiirovanie energoemkikh materialov [Laser initiation of energetic materials]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 15(4):87–93. doi: 10.30826/CE22150409.
7. Fang, X., and S. R. Ahmad. 2016. Laser ignition of an optically sensitised secondary explosive by a diode laser. *Cent. Eur. J. Energ. Mat.* 13:103–115. doi: 10.22211/cejem/64966.
8. Fang, X., M. Sharma, C. Stennett, and P. P. Gill. 2018. Optical sensitisation of energetic crystals with gold nanoparticles for laser ignition. *Combust. Flame* 183:15–21. doi: 10.1016/j.combust-flame.2017.05.002.
9. Konovalov, A. N., N. V. Yudin, V. I. Kolesov, and V. A. Ul'yanov. 2019. Increasing the heating efficiency and ignition rate of certain secondary explosives with absorbing particles under continuous infrared laser radiation. *Combust. Flame* 205:407–414. doi: 10.1016/j.combustflame.2019.04.026.
10. Dmitriev, A. K., V. I. Kolesov, A. N. Konovalov, V. S. Tiurina, V. A. Ul'yanov, and N. V. Yudin. 2018. Nagrev i vosplamenenie pirotekhnicheskikh kompozitsiy lazernym izlucheniem blizhnego infrakrasnogo diapazona [Heating and ignition of pyrotechnic compositions by near-infrared laser radiation]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 11(3):103–109.
11. Kirilenko, V. G., L. I. Grishin, A. Yu. Dolgoborodov, and M. A. Brazhnikov. 2020. Lazernoe initsiirovanie nanotermitov Al/CuO i Al/Bi_2O_3 [Laser initiation of nanothermites Al/CuO and Al/Bi_2O_3]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 13(1):145–155. doi: 10.30826/CE20130115.
12. Kolesov, V. I., A. N. Konovalov, E. S. Manakhova, V. A. Ul'yanov, and N. V. Yudin. 2020. Time delay of initiation of some primary explosives and initiating mixtures when exposed to continuous IR laser radiation. *Propell. Explos. Pyrot.* 45(11):1745–1754. doi: 10.1002/prep.202000128.
13. Fronabarger, J. W. 1974. Igniter composition comprising a perchlorate and potassium hexacyano cobaltate II. Patent US3793100A.
14. Abdrizyakov, V. N., D. S. Ustalov, M. A. Meshkov, *et al.* 2015. Tverdotoplivnyy zaryad dlya mikrodvigateley [Solid propellant charge for micromotors]. Patent RU2605482C2.
15. Chepurnoy, A. O., and V. Yu. Egorshev. 2016. Issledovanie goreniya melkodispersnykh smesey tsianokompleksov zheleza s neorganicheskimi okislitelyami [Study on combustion of fine-dispersed mixtures of iron cyano complexes with inorganic oxydizers]. *Uspekhi v khimii i khimicheskoy tekhnologii* [Advances in Chemistry and Chemical Technology] 30(8):64–67.
16. Fogelzang, A. E., V. P. Sinditskii, V. V. Serushkin, V. Y. Egorshev, Y. K. Shchipin, and V. A. Tropynin. 1995–1998. Combustion of explosives database flame. Version 2.4. Moscow.
17. Egorshev, V. Y., V. P. Sinditskii, and K. K. Yartsev. 2013. Combustion of high-density CuO/Al nanothermites at elevated pressures. *Autumn Seminar (International) on Propellants, Explosives and Pyrotechnics Proceedings*. Chengdu, China. 10:287–290.
18. Belov, G. V. 1983–2007. *REAL — programmnyy kompleks dlya modelirovaniya ravnovesnykh sostoyaniy termodinamicheskikh sistem pri povyshennykh znacheniyakh temperatury i davleniya* [REAL — software package for modeling equilibrium states of thermodynamic systems at elevated temperatures and pressures]. Moscow. 23 p.
19. Bagal, L. I. 1975. *Khimiya i tekhnologiya initsiiruyushchikh vzryvchatykh veshchestv* [Chemistry and technology of initiating explosives]. Moscow: Mashinostroenie. 455 p.
20. *Engineering design handbook*. 1971. Explosives ser. Properties of explosives of military interest. Explosives ser. Properties of explosives of military interest. — U.S. Government Printing Office. 706:177.
21. Knunyants, I. L. 1990. Khimicheskaya entsiklopediya [Chemical encyclopedia]. *Sovetskaya entsiklopediya* [Soviet Encyclopedia]. Ed. I. L. Knunyants. Moscow: Sovetskaya entsiklopediya. Vol. 2. 671 p.
22. Pechenyuk, S. I., D. P. Domonov, and A. N. Gosteva. 2021. Thermal decomposition of cationic, anionic, and double complex compounds of 3d-metals. *Russ. J. Gen. Chem.* 91(9):1834–1861. doi: 10.1134/S1070363221090310. EDN: HJUEUO.
23. Kunrath, J. I., C. S. Müller, and E. Frank. 1978. Thermal decomposition of potassium hexacyanoferrate (II) trihydrate. *J. Therm. Anal. Calorim.* 14(3):253–264. doi: 10.1007/bf01915163.
24. Chen, H., X. Xin, J. Niu, A. Dai, P. Tail, X. Wang, and Y. Zhang. 1988. *Chem. J. Chinese U.* 4:8.
25. Rabinovich, V. A., and Z. Ya. Khavin. 1978. *Kratkiy khimicheskiy spravochnik* [Brief chemical reference book]. 2nd ed. Leningrad: Khimiya. 316 p.
26. Sheludyak, E. Yu., L. Ya. Kashporov, L. A. Malinin, and V. N. Tsalkov. 1992. *Teplofizicheskie svoystva komponentov goryuchikh sistem. Spravochnik* [Thermophysical properties of components of combustible systems. Reference book]. Ed. N. A. Silin. Moscow: NPO Inform TEI. 184 p.

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