THERMAL EXPLOSION OF NEPE-TYPE COMPOSITE ENERGETIC MATERIAL

Yu. M. Milekhin[1], A. A. Koptelov[1], I. A. Koptelov[2], A. A. Rogozina[1], and N. I. Shishov[1]

[1]Federal Center for Dual Technologies "Soyuz," 42 Acad. Zhukova Str., Dzerzhinsky, Moscow Region 140090, Russian Federation
[2]Innovation Center "Barricades," 15 Druzhinnikovskaya Str., Moscow 123242, Russian Federation

Abstract: The times to thermal explosion τ of a mixed energetic material of the NEPE (Nitrate Ester Plasticized PolyEster) type were experimentally determined on samples in the form of cylinders with a diameter and a height of 4 mm, pressed into hermetic steel shells with a filling density close to theoretical. The experiments were carried out under isoperibolic conditions in the temperature range from 110 to 140 °C. The obtained experimental values of τ are compared with those calculated by the system of equations of thermal conductivity and kinetics using the kinetic characteristics obtained by the DSC (differential scanning calorimetry) method. It is shown that the results of experiments and numerical calculations are in the best agreement when using the formal kinetic equation of a branched chain reaction.

Keywords: thermal explosion; thermal decomposition; energetic material; nitrate esters; activation energy

DOI: 10.30826/CE22150310 **EDN:** KIVRDN

Figure Captions

Figure 1 Normalized DSC peaks of the plasticizer in the structure of material K-1 obtained in sealed crucibles (solid lines) and dependences $d\alpha/dT$ at heating rates $b = 0.1$, 0.35, and 1.0 K/min (from left to right) and values $j = 0.99999$ (*1*–*3*), and 0.999 ($1'$–$3'$)

Figure 2 Dependences of the rate of thermal decomposition of plasticizer of material K-1 on time calculated by Eq. (1) for $T = 120$ °C at $j = 0.999$ (*1*), 0.9999 (*2*), and 0.99999 (*3*). Solid lines — $n = 0$, $m = 1$; and dotted lines — $n = 1$, $m = 1$

Figure 3 Dependence of temperature in the center of a polymethyl methacrylate cylinder on time when the cylinder is placed in a thermostat preheated to 100 °C: signs — experiment; and curves — calculations at $H = 5$ (*1*), 10 (*2*), and 20 W/(m^2·K) (*3*)

Figure 4 Calculated dependences of the temperature in the center of the sample of material K-1 in the form of a ball on time at $T_S = 120$ °C: *1*–*3* — $F(T, t)$ according to Eq. (4) (first-order autocatalysis) at $\alpha_0 = 0.001$ (*1*), 0.0001 (*2*), and 0.00001 (*3*); and *4* — $F(T, t)$ according to Eq. (3) at $j = 0.999$

Figure 5 Dependence of the delay time of thermal explosion of material samples K-1 on the ambient temperature: *1* and *2* — calculation according to Eq. (2) with initial and boundary conditions (5) and (6) using the heat release function (3) (*1* — $j = 0.9999$ and *2* — $j = 0.999$); *3* — experimental data obtained in the explosive cells described above; and *4* — DSC data with samples weighing 1–2 mg

Figure 6 Experimental dependence of the delay time of thermal explosion of K-1 samples on temperature (signs) and its approximation by the function $y = K \exp[E/(Rx)]$ (curve)

References

1. Burnham, A. K., R. K. Weese, J. F. Wardell, T. D. Tran, A. P. Wemhoff, J. G. Koerner, and J. L. Maienschein. 2006. Can thermal analysis reliably predict thermal cookoff behavior? *13th Detonation Symposium (International) Proceedings*. Norfolk, VA. UCRL-CONF-222234.
2. Burnham, A. K., R. K. Weese, A. P. Wemhoff, and J. L. Maienschein. 2007. A historical and current perspective on predicting thermal cook-off behavior. *J. Therm. Anal. Calorim.* 89(2):407–415.
3. Wemhoff, A. P., W. M. Howard, A. K. Burnham, and A. L. Nichols. 2008. An LX-10 kinetic model calibrated using simulations of multiple small-scale thermal safety tests. *J. Phys. Chem. A* 112(38):9005–9011.
4. Milekhin, Yu. M., A. A. Koptelov, D. N. Sadovnichii, N. I. Shishov, T. A. Bestuzheva, and E. A. Butenko. 2006. Thermal decomposition of polyester polyurethane and its elastomers exposed to γ-radiation. *Combust. Explo. Shock Waves* 42(2):242–246.
5. Koptelov, A. A., Yu. M. Milekhin, A. A. Matveev, I. A. Koptelov, and A. A. Rogozina. 2017. Prediction of thermal explosion parameters for energetic materials on the basis of thermal analysis data. *Russ. J. Appl. Chem.* 90(8):1265–1272.
6. Vyazovkin, S., A. K. Burnham, J. M. Criado, L. A. Perez-

Maqueda, C. Popescu, and N. Sbirrazzuoli. 2011. ICTAC Kinetics Committee recommendations for performing kinetic computations on thermal analysis data. *Thermochim. Acta* 520:1–19.

7. Bohn, M. A. 2007. NC-based energetic materials — stability, decomposition, and ageing. *Nitrocellulose — Supply, Ageing and Characterization Meeting*. Aldermaston, England: AWE.
8. Koptelov, A. A., I. A. Koptelov, A. A. Matveev, and A. A. Rogozina. 2020. Raschet vremeni zaderzhki teplovogo vzryva energeticheskogo smesevogo materiala na polibutadienovom svyazuyushchem [Calculation of the delay time of thermal explosion of a mixed energetic material on polybutadiene binder]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 13(2):96–101.
9. Popok, V. N. and K. F. Ilinykh. 2013. Teplovoy vzryv smesevykh energeticheskikh materialov na osnove razlichnykh goryuchikh-svyazuyushchikh i okisliteley [Thermal explosion of mixed energy materials on the basis of various combustible binders and oxidizers]. *Butlerov Communications* 33(3):42–48.
10. Qin Pei-wen, Xiao-bin Zhao, Chao Qin, Li-guo Cheng, Jing Su, and Hong-bo Guan. 2016. Size effects of thermal safety of NEPE propellant. *Chinese J. Explosives Propellants* 39(1):84–88.

Received May 13, 2022

Contributors

Milekhin Yury M. (b. 1947) — Academician of RAS, director, Federal Center for Dual Technologies “Soyuz,” 42 Acad. Zhukova Str., Dzerzhinsky, Moscow Region 140090, Russian Federation; soyuz@fcdt.ru

Koptelov Alexander A. (b. 1945) — Doctor of Science in technology, chief research scientist, Federal Center for Dual Technologies “Soyuz,” 42 Acad. Zhukova Str., Dzerzhinsky, Moscow Region 140090, Russian Federation; aakoptelov@gmail.com

Koptelov Igor A. (b. 1975) — president, Innovation Center “Barricades,” 15 Druzhinnikovskaya Str., Moscow 123242, Russian Federation; igor.koptelov@mail.ru

Rogozina Anna A. (b. 1991) — head of group, Federal Center for Dual Technologies “Soyuz,” 42 Acad. Zhukova Str., Dzerzhinsky, Moscow Region 140090, Russian Federation; npi-2013@bk.ru

Shishov Nikolay I. (b. 1946) — Doctor of Science in technology, head of department, Federal Center for Dual Technologies “Soyuz,” 42 Acad. Zhukova Str., Dzerzhinsky, Moscow Region 140090, Russian Federation; soyuz@fcdt.ru