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IGNITION OF INITIATORS BY AN ELECTRICAL SPARK

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Foreign Technology Division
Wright-Patterson Air Force Base, Ohio

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by

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

IGNITION OF INITIATORS BY AN ELECTRICAL SPARK

A. I. Gavrilin, M. A. Mel'nikov, and
V. B. Sheyder

Tomsk

At present there are two contradictory opinions on the initiation of inorganic azides by an electrical spark. On the one hand, authors of a number of works [1-3] put thermal effects connected with the development of the discharge channel in the first position and show that initiation of the reaction occurs only when in the spark channel a certain minimal energy is released. On the other hand, in works [4, 5] the main role is taken by the rapid reactions of the excited particles, and the nonthermal mechanism of excitation of the detonation process is assumed possible.

The experimental data available at the present time make it possible to speak about the existence of a minimal volume of the center of warm-up, with the achievement of the critical value of the density of energy in which further independent development of the process is possible.

The use of the cutoff diagram, which allows measuring the entry of energy into the discharge channel, made it possible to conduct direct measurement of the radius of the center, which consisted of 20-30 μ. A decrease in the rate of the input of energy leads to an increase in the delay time with a constancy of energy necessary for the initiation and approximate constancy of the dimension of the center.

All these experimental data allow assuming that the ignition process appears not in direct contact of the substances with the high-temperature discharge channel, but on the interface with removal of it at the distance $r = r_{эф}$ and the reaching of the energy density $\varepsilon = \varepsilon_{опт}$.

Proceeding from that stated above, within the framework of the heat theory of ignition it is possible to examine the processes occurring on the effective surface. Experimental studies of the change in the brightness of glow of the discharge channel with time in the interval from the beginning of breakdown to the beginning of detonation make it possible with a sufficient degree of accuracy to consider the nature of the increase in temperature of the spark and, consequently, the temperature of the examined point of the surface to be linear.

The given approach does not give the possibility of a complete analytical calculation of all the characteristics of ignition and is used as a model for confirmation of the thermal mechanism of the excitation of detonation in the inorganic azides.

Mathematically the problem is reduced to the solution of the equation of thermal conductivity [6]

$$cp \cdot \frac{\partial T}{\partial t} = \lambda \cdot \frac{\partial^2 T}{\partial x^2} + Qk_0 e^{-\frac{E}{RT}},$$

where λ - coefficient of thermal conductivity; ρ - density of the substance; k_0 - pre-exponent; c - specific heat; Q - thermal effect; with the initial and boundary conditions

$$T(0, x) = T_н; \quad T(0, t) = T_н + kt;$$
$$T(\infty, t) = T_н; \quad \frac{\partial T(\infty, t)}{\partial x} = 0,$$

where k - rate of heating; $T_н$ - initial temperature.

In dimensionless coordinates

$$\frac{\partial \Theta}{\partial \tau} = \frac{d^2\Theta}{d\xi^2} + e^{\Theta}; \quad \Theta(0, \tau) = \Theta_н + A\tau;$$
$$\Theta(0, \xi) = \Theta_н; \quad \Theta(\infty, \tau) = \Theta_н$$

where

$$\Theta = \frac{E}{RT_*^2}(T - T_*) \quad \text{(dimensionless temperature);}$$
$$\Theta_н = \frac{E}{RT_*^2}(T_н - T_*) \quad (T_* \text{ - flash temperature});$$
$$\tau = \frac{t}{t_a}; \quad t_a = \frac{RT_*^2}{E} \cdot \frac{c\rho}{Qk_0} e^{\frac{E}{RT_*}} \quad \text{(adiabatic time of induction);}$$
$$\xi = \frac{x}{x_a}; \quad x_a = \sqrt{\varkappa t_a} \quad \text{(length of thermal relaxation);}$$
$$A = \frac{kc\rho}{Qk_0} e^{\frac{E}{RT}}.$$

The solution of the steady-state equation on the limit of ignition gives the value of the critical gradient

$$\frac{\partial^2\Theta}{\partial\xi^2} = -e^{\Theta}; \quad \frac{\partial\Theta}{\partial\xi} = U;$$
$$\frac{\partial U}{\partial\Theta} = \frac{\partial U}{\partial\Theta} U = e^{-\Theta}; \quad \frac{U^2}{2}\Big|_{\xi=\xi_1>0} - \frac{U^2}{2}\Big|_{\xi=0} = -(1 - e^{\Theta})$$

on the surface $\xi = 0; \Theta = 0; \frac{\partial\Theta}{\partial\xi} = 0;$

$$-U = -\frac{\partial\Theta_c}{\partial\xi}\Big|_{\xi=\xi_1} = \sqrt{2(1 - e^{\Theta})}$$

when $\xi \to \infty; \quad \Theta \to -\infty; \quad \lim_{\xi\to-\infty} \frac{\partial\Theta_c}{\partial\xi} = -\sqrt{2}.$

The solution of the linear equation in the region of heating with the assigned initial and boundary conditions has the form

$$\frac{\partial\Theta}{\partial\tau} = \frac{\partial^2\Theta}{\partial\xi^2};$$

$$\Theta(\xi, \tau) = \Theta_н + \Theta_н\left(1 - \operatorname{erf}\frac{\xi}{2\sqrt{\tau}}\right) +$$

$$+ A\left[\left(\tau + \frac{\xi^2}{2}\right)\left(1 - \operatorname{erf}\frac{\xi}{2\sqrt{\tau}}\right) - \xi\sqrt{\frac{\tau}{\pi}}\cdot e^{-\frac{\xi^2}{4\tau}}\right];$$

$$\left.\frac{\partial\Theta_з}{\partial\xi}\right|_{\xi=0} = -\frac{2}{\sqrt{\pi}}\left[\Theta_н + A\left(\tau + \frac{\sqrt{\tau}}{2}\right)\right].$$

The condition of the reaching of the critical gradient

$$\left.\frac{\partial\Theta_з}{\partial\xi}\right|_{\xi=0} = \left.\frac{\partial\Theta_с}{\partial\xi}\right|_{\xi\to\infty};$$

$$-\frac{2}{\sqrt{\pi}}\left[\Theta_н + A\left(\tau + \frac{\sqrt{\tau}}{2}\right)\right] = -\sqrt{2}.$$

On the limit of ignition $\Theta = 0$, then $-\Theta_н = A_\tau$.

Hence $A = -\frac{\Theta_н}{\tau}$.

Using this relation, we obtain

$$\tau_з = \frac{\Theta_н^2}{2\pi} \text{ and } A = \frac{2\pi}{|\Theta_н|}.$$

In passing to the dimensional form, we obtain

$$t_з = \frac{1}{2\pi}\cdot\frac{E}{TR_*^2}(T_* - T_н)^2\,\frac{c\rho}{Qk_0}\,e^{\frac{E}{RT_*}} \quad (t_з \text{ - time of ignition}). \qquad (1)$$

$$\frac{kc\rho}{Qk_0}\,e^{\frac{E}{RT_*}} = \frac{2\pi RT_*^2}{E(T_* - T_н)}. \qquad (2)$$

The complex $kc\rho = \varepsilon_1$ determines the specific power of the external source.

The two equations obtained contain three unknown quantities T_*, ε_1, and $t_з$. Knowing one of them makes it possible to calculate the other two and compare them with the experimental data.

The delay times of the explosion at a different current density and, consequently, different specific power of the energy source were determined experimentally. The current density in the spark was changed by means of inclusion into the discharge circuit, in series with the specimen, of the active resistance. Simultaneously determined were the energies necessary for the initiation of the specimens and also in a number of experiments - the effective radius of the spark channel by means of its direct measurement on the preserved specimens. By knowning $r_{эф}$, $\varepsilon_{мин}$, and $t_з$, it is possible to determine the specific power of the external source and compare it with the calculated value.

The determination of T_* was produced by means of extrapolation of the relation $\varepsilon_{мин} = f(T)$ up to zero energy of initiation. All the experiments were conducted with specimens with a density of $\rho = 2.5$ g/cm^3 with a distance between the electrodes of $l = 0.1$ mm.

Results of the calculation and experimental data are given in Fig. 1. For a comparison the relation $t_з = f(T)$, calculated according to formula $\ln \tau = \frac{A}{T_0} + B$ [1] (3), obtained without taking heat losses into account, is plotted. From the given relations, it is evident that this formula gives an overstated value of the flash temperature of the substance, and formula (1) - values somewhat understated but closer to the experiment.

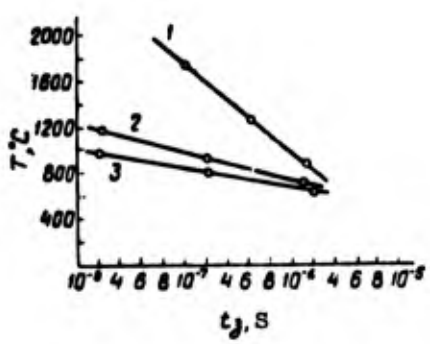

Fig. 1. Dependence of flash temperature on delay time of the explosion: 1 - calculation by formula (3); 2 - experimental data; 3 - calculation by formula (1).

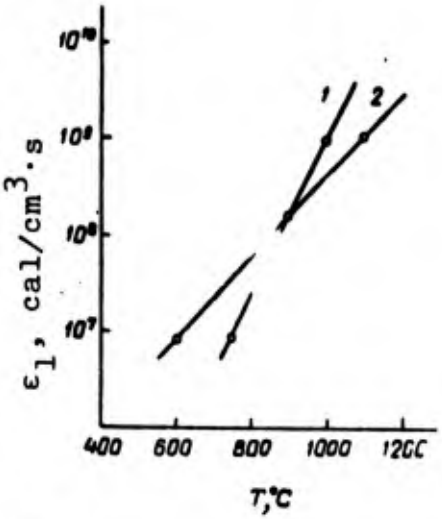

Fig. 2.

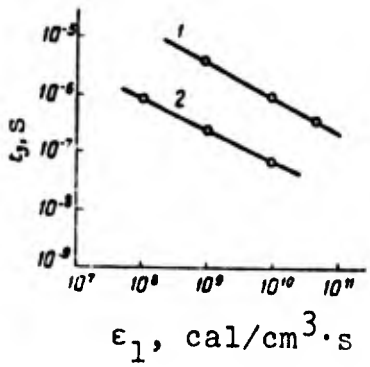

Fig. 3.

Fig. 2. Dependence of the specific power of the source on the flash temperature: 1 - experimental data; 2 - calculation by formula (2).

Fig. 3. Dependence of the delay time of the explosion on the specific power of the source: 1 - experimental data; 2 - calculation by formulas (1) and (2).

Dependences of the flash temperature on the specific power of the external source are given on Fig. 2. The effect of ε_1 on the flash temperature of the substance, all other conditions of the conducting of the experiment being equal, is clearly evident. Certain divergences in the shape of the experimental and calculated dependences should, in the first place, be referred to the error in determining $r_{эф}$ and $\varepsilon_{мин}$.

Figure 3 shows the effect of the specific power on the ignition time. Qualitatively the experimental and calculated curves repeat each other; however, divergences of experimental and calculated data are essential, which is explained by the difference in time of the delay of the explosion, which corresponds to the same temperature on curves 2 and 3 (Fig. 1). The dependences represented clearly show the effect of the specific power of the energy source on the ignition characteristic. The good convergence of results of the experiment with the calculated dependences confirms the thermal nature of the initiation of azides by electrical spark.

However, it should be noted that the assignment of the indicated temperature profile on the critical surface is not completely correct, since the spark as a thermal source does not give a monotonically increase in temperature on the interface of the phases. But the examined simple model helps more deeply to understand the physics of the phenomenon and determine with sufficient accuracy a number of characteristics of ignition.

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