TIME TO IGNITE A GAS WITH A FRICTION SPARK

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The authors examine a simplified model of unsteady thermal ignition of a gas by a friction spark (or a hot body) in order to find the ignition time.

The time to ignite a gas with a friction spark [1] is calculated from the moment the spark enters the gas until the flame appears. It is found by solving a system of equations of heat conduction, diffusion and chemical kinetics.

Depending on the temperature ratio of the igniting body and of gas combustion, three regimes are observed: 1) for $T_s\sqrt{2}<T_c$ induction; 2) for $T_s\approx T_c$ intermediate; 3) for $T_s>T_c$ ignition regime [2]. In case 1 we can neglect combustion of the components, and in case 2 the profiles of concentration and temperature are similar. Therefore, the system reduces to a single heat-conduction equation.

To analytically determine the time to ignite a gas with a heated body for $T_s\sqrt{2}<T_c$, we use the method of Zeldovich [3], approximate solution of the unsteady heat-conduction problem

$$\frac{\partial\Theta}{\partial\tau}=\frac{1}{\xi^2}\frac{\partial}{\partial\xi}\xi^2\frac{\partial\Theta}{\partial\xi}+\exp\Theta/(1+\beta\Theta),$$
$$\Theta(\xi_s,\ \tau)=0,\ \Theta(\xi,\ 0)=\Theta_0,\ \Theta(\infty,\ \tau)=\Theta_0, \tag{1}$$

describing the temperature field in the lean hot component of the gas mixture surrounding a spherical heated particle. Postulating that in a thin layer adjacent to the particle surface the gas temperature instantly acquires a steady value, we write the heat-conduction equation for region (1) ($\xi_s<\xi<\xi_s+\delta$) at

$$\frac{1}{\xi^2}\frac{\partial}{\partial\xi}\xi^2\frac{\partial\Theta_1}{\partial\xi}+\exp\Theta_1/(1+\beta\Theta_1)=0 \tag{2}$$

with the boundary conditions

$$\Theta_1(\xi_s)=0,\ \left.\frac{\partial\Theta_1}{\partial\xi}\right|_{\xi=\xi_s}=0, \tag{3}$$

the last of which is the ignition condition.

Transforming the second term of Eq. (2) by the method of Frank-Kamenetskii [4], and taking into account that the thickness of the chemical reaction zone is much less than the particle radius ($\delta\ll\xi_s$), it is not difficult to show that Eq. (2) can be represented in the form

$$\frac{\partial^2\Theta_1}{\partial\xi^2}+\exp\Theta_1=0. \tag{4}$$

Hence the heat flux from region (1) to the cold gas mixture is

$$\left.\frac{\partial\Theta_1}{\partial\xi}\right|_{\xi_s+\delta-0}=-\sqrt{2(1-\exp\Theta_\delta)}\approx-\sqrt{2}, \tag{5}$$

since $\exp\Theta_\delta\ll 1$.

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For region (2) ($\xi_s+\delta<\xi<\infty$) we neglect the action of sources resulting from chemical reaction. In a time interval equal to the ignition time, we solve the equation

$$\frac{\partial\Theta_2}{\partial\tau}=\frac{1}{\xi^2}\frac{\partial}{\partial\xi}\xi^2\frac{\partial\Theta_2}{\partial\xi} \tag{6}$$

with the conditions

$$\Theta_2(\xi_s+\delta,\ \tau)\approx\Theta(\xi_s,\ \tau);\ \Theta_2(\infty,\ \tau)=\Theta_0;\ \Theta(\xi,\ 0)=\Theta_0. \tag{7}$$

The solution of the problem of Eqs. (6) and (7) as $\delta\to 0$ has the form

$$\Theta_2(\xi,\ \tau)=\Theta_0-\Theta_0\frac{\xi_s}{\xi\sqrt{\pi\tau}}\int\limits_{\xi-\xi_s}^{\infty}\exp(-\eta^2/4\tau)\,d\eta.$$

The heat flux at the surface $\xi=\xi_s+\delta$ is:

$$\left.\frac{\partial\Theta_2}{\partial\xi}\right|_{\xi=\xi_s+\delta+0}\approx\Theta_0\left(\frac{1}{\xi_s}+\frac{1}{\sqrt{\pi\tau}}\right). \tag{8}$$

Using the condition of equal heat flux at the boundary of the heating zone and the chemical reaction zone

$$\left.\frac{\partial\Theta_1}{\partial\xi}\right|_{\xi=\xi_s+\delta-0}=\left.\frac{\partial\Theta_2}{\partial\xi}\right|_{\xi=\xi_s+\delta+0}$$

and Eqs. (5) and (8), for the dimensionless ignition time we obtain

$$\tau_d=\frac{1}{\pi}\left(\frac{\xi_s\Theta_0}{\sqrt{2}\xi_s+\Theta_0}\right)^2. \tag{9}$$

We shall express the dependence of the ignition delay time on the radius of the heated particle and the physical and chemical properties of the gas mixture in the dimensional form

$$t_d=\frac{1}{\pi a}\left(\frac{r_s r_*}{r_s-r_*}\right)^2, \tag{10}$$

where

$$r_*=\sqrt{\frac{\lambda_g(T_s-T_0)^2E\exp E/RT_s}{2RT_s^2qk_0\rho_gC_0}}. \tag{11}$$

It is not difficult to show that in the intermediate regime ($T_s \approx T_c$)

$$r_*=\sqrt{\frac{\lambda_g(T_s-T_0)^3E^2T_s\exp E/RT_s}{2(RT_s^2)^2qk_0\rho_gT_0C_0}}. \tag{12}$$

As we decrease the radius of the heated particle ($r_s\to r_*$) t_d increases, tending to ∞. For $r_s<r_*$ the particle does not ignite the gas mixture. If we formally apply $r_s\to\infty$, then from Eq. (10) we have the solution $t_d=r_*^2/\pi a$, obtained in [3], which is found to agree satisfactorily with the results of [5].

NOTATION

$\Theta=E(T-T_s)/RT_s^2$, dimensionless temperature; $\beta=RT_s/E$, dimensionless parameter; $\xi=r/x_a$, dimensionless coordinate; $x_a=\sqrt{\frac{\lambda_gRT_s^2\exp E/RT_s}{Eqk_0\rho_gC_0}}$, characteristic dimension; $\tau=t/t_x$, dimensionless time; $t_x=x_a^2/a$, characteristic time; T, temperature; t, time; r, current radius; r_s, particle radius; δ, dimensionless thickness of the chemical reaction zone; C, relative mass concentration of the combusting component in the gas; a, thermal diffusivity; λ, thermal conductivity; R, universal gas constant; E, activation energy; q, thermal effect of the reaction per unit mass of the combusting component; k_0, preexponent; ρ_g, gas density. Subscripts: r, combustion; s, particle surface; d, delay; 0, initial conditions; g, gas; 1, 2) reaction regions.

LITERATURE CITED

1. V. S. Kravchenko and V. A. Bondar (eds.), Explosive Safety of Electrical Discharge and Friction Sparks [in Russian], Nedra, Moscow (1976).
2. A. G. Merzhanov, B. I. Khaikin, and G. K. Shkadinskii, "Establishing a steady flame distribution during ignition of a gas with a heated surface," Zh. Prikl. Mekh. Tekh. Fiz., No. 5, 42-48 (1969).
3. Ya. B. Zel'dovich, "A theory of ignition," Dokl. Akad. Nauk SSSR, 150, No. 2, 283-285 (1963).
4. E. S. Shchetnikov, Physics of Gas Comubstion [in Russian], Nauka, Moscow (1965).
5. V. N. Viklyunov and L. B. Sidonskii, "A theory of ignition of condensed systems by a hot surface," Dokl. Akad. Nauk SSSR, 152, No. 1, 131-133 (1963).

STABILITY OF THE MAGNETIC PROPERTIES OF IRON—COBALT ALLOY AT DIFFERENT ANNEALING TEMPERATURES

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The article presents the results of experimental investigations of the effect of the annealing temperature on the stability of the magnetic properties of the Fe—Co—2Mn alloy.

When highly homogeneous magnetic fields are required, magnetic materials are used which have high saturation induction and whose magnetic properties in operation are very stable. Among these materials are the iron—cobalt alloys type Permendur which at present are widely used in various fields of instrument making. The alloys Fe—Co—2V, Fe—Co—2Mn with additives V and Mn are used for making magnetic lenses of electron microscopes, pole shoes for NMR high-resolution radiospectrometers, and other instruments in radio electronics and computer technology. A number of authors [1-15] investigated these alloys to study the effect of the conditions of plastic deformation, of thermomagnetic and other kinds of treatment on their magnetic properties and on the homogeneity of the structure. The source of inhomogeneity of the magnetic field, which limits the resolution of the instruments, is the course crystal structure of the material [5, 8]. A fine-grained structure of iron—cobalt alloys is attained by adding some alloying elements to them [8]. The structure can also be improved [3, 4, 12] by choosing the optimal regime of heat treatment. Investigations [3, 4, 14, 15] showed that it is possible to attain an axial texture when certain deformation procedures are applied, and that textured pole shoes in NMR radio spectrometers can be used.

The above-mentioned authors showed that by using various kinds of treatment it is possible to improve the magnetic properties of iron—cobalt alloys. Further improvement of the resolution of instruments is not only attained by reducing the inhomogeneity of the field but also as a result of increasing the stability of the magnetic properties in time [6].

In connection with the widespread practical application of these alloys the study of the stability of their magnetic properties in time with different kinds of mechanical, thermal, thermomagnetic treatment is of practical and scientific interest. The articles [9, 10] report on investigations of the stability of the magnetic properties of specimens of Fe—Co—2V alloy for the range of annealing temperatures encompassing all the characteristic regions of the phase diagram [2, 7]. The data of [9] show that when the annealing temperature

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