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PREVENTION OF PREVIOUS OPERATION OF CHARGES OF PYROTECHNICAL PRODUCTS BASED ON MIXTURES OF MAGNESIUM, ALUMINUM POWDER AND METAL WASTE IN THE CONDITIONS OF EXTERNAL THERMAL ACTIONS

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ABOUT ARTICLE

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ANNOTATION

Mathematical models of external heating of charges of pyrotechnic products based on compacted mixtures of aluminium-magnesium alloy powders and nitrate-containing oxidizers (sodium, potassium, strontium, and barium nitrates) were refined by taking into account the temperature dependence of their thermophysical properties (volumetric heat capacity and coefficient of thermal conductivity), which allowed to more accurately determine the critical values of heat flows and durations of their influence [1–2]. New data were obtained to determine the critical ranges of the change in the burning rate of mixtures under conditions of elevated heating temperatures and external pressures for various values of technological parameters (the coefficient of excess oxidizer α ; the average particle size of metal fuel powders d_m microns and oxidizer d_N), exceeding the ranges of which leads to premature ignition mixtures under conditions of external thermal effects and leads to unstable explosive development of their combustion process and fire-hazardous destruction of pyrotechnic products

Problem statement. Pyrotechnic products (PP) based on compacted two-component mixtures of aluminum-magnesium alloys (AMA) and nitrate-containing oxidizers (sodium, potassium nitrates, etc.) are widely used to organize the burning process of multicomponent pyrotechnic mixtures. These mixtures are widely used in the national economy and military equipment [3–4]. AMA mixtures are equipped with products for various purposes (illuminating cartridges and artillery shells, photo-illuminating aerial bombs, signal projectiles, pyrotechnic IR projectiles (infrared targets-traps of modern thermally guided missiles, etc. [5–6])). At the same time, the products may be exposed to intense external thermal effects during storage, transportation and use. The surfaces of the products in such

conditions are exposed to significant local heaters, which leads to the premature activation of PV charges and the acceleration of the burning process under conditions of elevated heating temperatures, external pressures, etc., which in turn leads to fire-hazardous destruction of the products, ignition of surrounding objects, human victims, and causes significant material losses.

Therefore, an urgent problem is the development of methods to prevent the occurrence of forced fire-hazardous destruction of pyrotechnic products in the event of exposure to external thermal effects. For the development of such methods, it is necessary to have the results of studies of the processes of external heating, ignition and development of combustion of compacted

mixtures that make up the basis of pyrotechnic products, with the determination of their explosive modes of flow under different external conditions.

The relevance of this work lies in the fact that, based on the developed models, the premature triggering of pyrotechnic products based on mixtures of magnesium powders, aluminium and metal oxides is eliminated under conditions of external thermodynamics.

Analysis of recent research and publications. Data on the interaction of aluminium, zirconium, and titanium powders with environmental oxygen are presented in [7]. It was established that they ignite under heating conditions. At the same time, the ignition temperature of metals significantly depends on their dispersion ($d_m = 5...310$ microns), the relative concentration of oxygen in the environment ($C_{O_2} = 0,21(\text{air})...0.8$) and can vary in the range of 700...1900 K. The influence of ambient pressure on the process of their ignition, as well as the behaviour of the considered AMA powders, was not investigated.

The work [8] provides data on the influence of the dispersion of high-energy metals (magnesium, aluminium), as well as their content in pyrotechnic compositions based on a nitrate-containing oxidizer (ammonium nitrate). It is shown that an increase in the dispersion of the metal powder (for example, by 3...4 times - for magnesium and by 5...6 times - for aluminium) leads to explosive ignition of the specified compositions for the ratio of components close to stoichiometric (the coefficient of excess oxidant $\alpha = 1,0$). At the same time, replacing aluminium with magnesium only contributes to the explosive ignition of compositions. The process of the behaviour of the considered AMA powders in decomposition products of other nitrate-containing oxidants (for example, sodium, potassium nitrates, etc.) has not been investigated.

Data on the ignition of pyrotechnic mixtures based on aluminium powders by a laser beam are presented in [9]. The critical parameters of laser radiation (power, action time, wavelength) that lead to focal ignition

of mixtures have been established. It is shown that increasing the dispersion of aluminium powder (for example, by 3...4 times) reduces the ignition delay of mixtures by 1.5...2 times. At the same time, the influence of environmental parameters (oxygen content, heating temperature, external pressure) on the ignition process of mixtures was not considered. There are no similar studies for mixtures based on AMA powders. At the same time, the simulation of the heating process is considered only in a narrow zone of the laser beam, and not over the entire surface of the mixtures, as is the case, for example, in the case of fires in warehouses or when launching products with the considered pyrotechnic products.

The work [10] presents a study of the ignition mechanism of ultrafine aluminium powders in the decomposition products of pyrotechnic compositions on ammonium perchlorate. It was established that the ignition process of an individual metal particle begins on its surface, and then, after melting aluminium, passes into the gas phase. Comparison of the results of the calculations of the dependences of the ignition temperature of a metal particle on its size and the oxygen content in the decomposition products with the experiment showed their complete correspondence (the relative error does not exceed 5...7%). At the same time, the influence of ambient temperature and external pressure on the processes of ignition of ammonium particles remained unresolved. In addition, ignition processes of other high-energy metals (for example, magnesium, AMA) in decomposition products of not only ammonium perchlorate, but also nitrate-containing oxidants have not been investigated.

New data on the behaviour of magnesium powders in active gaseous media (oxygen, air, etc.) and in pyrotechnic mixtures with oxygen-containing oxidants under their heating conditions (for example, during fires in warehouses, during transportation, etc.) are presented in [11]. The dependence of the temperature and ignition delay of magnesium powders on their dispersion has been established. So, for example, when the

average size of metal particles increases by 4...5 times, the ignition temperature and the delay time in air decrease by 2...2.5 times. Ignition of magnesium powders in mixtures with oxidants occurs in their decomposition products and is subject to the same laws. At the same time, the effect of the nature of the oxidant due to the relative oxygen content in their decomposition products was not investigated. The effect of temperature, pressure and composition of the environment on the specified ignition characteristics of magnesium powders has also not been clarified. There are no specified studies for AMA powders either.

Data on the ignition of high-energy pyrotechnic compositions based on ultrafine powders of metals (magnesium, aluminium, zirconium) and ammonium perchlorate are provided in [12]. It was established that the ignition of metals occurs in the decomposition products of the oxidizer and depends significantly on the dispersion of metal powders. Thus, with an increase in their dispersion, for example, by 3...5 times, their ignition temperature decreases by 2.5...3 times and lies in the range of 600...1900 K. The influence of the composition and environmental pressure on the ignition of the considered metals has not been considered. Also, the ignition process of AMA powders under the specified conditions has not been investigated.

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Data on the ignition of solid metallized fuels based on aluminium and titanium powders are presented in [13]. It was established that the ignition temperature of fuels significantly depends on the ratio of components, the dispersion of metal fuel powders (d_m , microns) and the coefficient of excess oxidant α). Thus, an increase in d_m by 5...6 times and α from 0.2 to 0.8 leads to a decrease in the ignition temperature by 2...3 times, and the range of its change is 1000...2000 K. There are no data on the ignition delay time of fuels, the effect on the characteristics their exposure to external conditions (temperature of heating, composition and pressure of the environment, etc.). The specified studies have not been conducted for fuels based on pyrotechnic mixtures based on AMA powders.

The paper [14] provides a comparative analysis of the combustion development rates of pyrotechnic compositions based on ultrafine aluminium powders. It has been established that the coefficient of excess oxidant in the mixture, the dispersion of aluminium powders and oxygen-containing oxidants (perchlorates, chlorates, etc.) have a significant influence on their burning speed. A decrease in the dispersion of the metal fuel and oxidizer by 3...4 times leads to an increase in the burning rate by 1.5...3 times for $\alpha = 1,0$. When α increases from 0.6 to 1.5, the burning rate decreases by 1.5...2 times. There are no studies of the effect of heating temperature and external pressure on the burning rate of the considered mixtures. There are no data on the burning rates of mixtures based on AMA powders.

The paper [15–16] provides data on the main characteristics of the flames of solid pyrotechnic compositions based on aluminium powders and ammonium perchlorate (on the temperature T_b and the composition of combustion products, the content of high-temperature condensate gc , etc.). It was established that the specified characteristics depend most significantly on the ratio of components in the initial mixtures. So, for example, T_b has maximum values in the range of 3500...4500 K at $\alpha = 0.9...1.0$, and value = 0.5...0.7 at $\alpha = 0.2...1.5$. There are

no data on the characteristics of flames of compositions based on mixtures of AMA powders.

In [17], the dependence of the speed and limit modes of combustion of two-component mixtures of titanium powders and nitrate-containing oxidizers (NaNO_3 , $\text{Ba}(\text{NO}_3)_2$, $\text{Sr}(\text{NO}_3)_2$) on technological parameters under conditions of elevated heating temperatures and external pressures was investigated. It was established that an increase in the heating temperature to 800 K and external pressure to 107 Pa leads to an increase in the burning rate by 1.5...3.5 times. An increase in the coefficient of excess oxidant from 0.35 to 1.4, as well as the average particle size of titanium powder from 45 microns to 280 microns and oxidant from 50 microns to 140 microns reduce its value by 2...4 times. On the basis of the obtained data, experimental-statistical models were developed to determine the unstable modes of development of combustion of the considered nitrate-titanium mixtures under the specified conditions. There are no similar data for nitrate pyrotechnic mixtures based on AMA powders.

Thus, currently there are no data on the developed mathematical models of external thermal effects on the charges of pyrotechnic products, which allow determining the critical values of their parameters (for example, heat flows, their action times, etc.), exceeding which can lead to their premature ignition and the development of an explosive combustion. There is also very limited or no information on the main characteristics of the combustion process of pyrotechnic products (temperature and ignition delay time of metal fuel particles in the decomposition products of oxidizers, the speed of development of the combustion process of products) under conditions of elevated heating temperatures and external pressures, which are realized in the case of premature activation of products. This significantly limits the possibilities of building adequate experimental and statistical models for determining the critical ranges of change in the burning rate of the considered products, which do not lead to an unstable explosive course of the burning process under the mentioned conditions.

Therefore, at the moment, there are no scientifically based methods for preventing the premature activation of pyrotechnic products based on mixtures of AMA powders with the subsequent explosive development of their combustion, which leads to fire-hazardous destruction of pyrotechnic products during their storage, transportation and launch (thermal shock effects in the conditions of a shot and flight).

The purpose of the article. The purpose of this work is to establish the main regularities of the processes of heating, ignition and combustion development of pyrotechnic products based on mixtures of AMA powders. Such studies make it possible to develop mathematical and experimental-statistical models for determining critical ranges of changes in the parameters of external thermal actions and rates of development of combustion of pyrotechnic mixtures, exceeding which can lead to premature ignition and explosive development of combustion of pyrotechnic mixtures, fire-hazardous destruction of products. Determining these ranges at the stages of manufacturing pyrotechnic products and bench tests of products will prevent their premature activation and the occurrence of fires in the event of external thermal effects.

Research methods. To study the influence of elevated heating temperatures (up to 800 K) and external pressures (up to 107 Pa) on the processes of ignition and development of combustion of pyrotechnic products, the following methods were used [3]: modern methods of physical and chemical analysis (film and microfilming methods, X-ray analysis methods, non-contact and contact methods of temperature measurement), methods of nonlinear thermal conductivity and thermal resistance, as well as mathematical and experimental-statistical modelling, mathematical and experimental-statistical modelling, standard pyrotechnic equipment for testing samples of pyrotechnic products under the specified conditions.

Calculations according to the models are carried out in real-time and dialogue mode using computer equipment that meets modern requirements for the use of special software.

Presenting main material. Thermal calculations are based on a complex of non-linear non-stationary mathematical models, which were refined by taking into account the shape and dimensions (flat layer, cylindrical layer), temperature dependence of the thermophysical properties of the PS (volumetric heat capacity $CV(T) = CV_0 \cdot T^v$ and thermal conductivity coefficient $\lambda(T) = \lambda_0 \cdot T^v$, де CV, λ_0, v – are empirical constants [3]). Moreover, only heat exchange by heat transfer was taken into account (convective and radiant types of heat

exchange were not considered due to their insignificance [2–3]).

To calculate the process of heating the charges of pyrotechnic products, standard equations of thermal conductivity were used, which were refined by the authors by taking into account the geometric dimensions of the charges and the dependences of $CV(T)$ та $\lambda(T)$. Using the standard method of integral Fourier transformations [2], analytical expressions for determining temperature distributions in the considered mixtures were obtained from model equations (Table 1).

Table 1 – Analytical expressions for determining the temperature distribution in charges of pyrotechnic products ($q_n = q_{n0} = \text{const}$)

Pyrotechnic Mixture	Analytical Expression for Determining the Temperature Distribution
A flat layer on the end surface of the mixture charge	$T(z,t) = (T_0^{v+1} + \frac{(v+1) \cdot q_{n0}}{\lambda_0} \cdot [\frac{a_0^2 \cdot t}{H} + \frac{3z^2 \cdot H^2}{6H} + \frac{2H}{\pi^2} \cdot \sum_{n=1}^{\infty} (-1)^{n+1} \cdot \frac{\cos \frac{\pi n z}{H}}{n^2} \cdot e^{-\frac{(\frac{\pi a_0 n}{H})^2 \cdot t}{v+1}}])^{\frac{1}{v+1}}, n = 3 \dots 5$
Cylindrical layer on the side surface of the mixture charge	$T(r,t) = T_0^{v+1} + \frac{(v+1) \cdot q_{n0} \cdot R_2}{\lambda_0} \cdot [\frac{R_2^2 \cdot t}{R_2^2 - R_1^2} \cdot (\frac{2a_0^2 \cdot t}{R_2^2} - \frac{1}{4} \cdot (1 - \frac{r^2}{R_2^2}) - \frac{R_1^2}{R_2^2} \cdot (\ln \frac{r}{R_1} + \frac{R_2^2}{R_2^2 - R_1^2} \cdot \ln \frac{R_1}{R_2} + \frac{3}{4})) + \sum_{n=1}^{\infty} \frac{\pi}{\mu_n} \cdot \frac{I_1(\mu_n \cdot \frac{R_1}{R_2}) \cdot I_1(\mu_n)}{I_1^2(\mu_n \cdot \frac{R_1}{R_2}) - I_1^2(\mu_n)} \cdot (I_0(\mu_n \cdot \frac{r}{R_2}) \cdot Y_1(\mu_n \cdot \frac{R_1}{R_2}) - Y_0(\mu_n \cdot \frac{r}{R_2}) \cdot I_1(\mu_n \cdot \frac{R_1}{R_2})) e^{-\frac{(\frac{\mu_n \cdot a_0}{R_2})^2 \cdot t}{v+1}}] \Bigg]^{\frac{1}{v+1}}, n = 5 \dots 7$

Note. r, z, t – coordinates and time of thermal exposure; T_0, a_0^2, H – initial temperature, coefficient of thermal conductivity and thickness (for a flat layer) of PP charge; R_1, R_2 – inner and outer radii of the cylindrical layer; I_0, I_1, Y_0, Y_1 – Bessel functions; μ are the roots of the characteristic equation $I_1(\mu \cdot \frac{R_2}{R_1}) \cdot Y_1(\mu) = Y_1(\mu \cdot \frac{R_1}{R_2}) \cdot I_1(\mu)$.

Determination of critical values of thermodynamic parameters taking into account the temperature dependence of thermophysical properties of products.

As a result of the conducted research (Figs. 1, 2) it was established that the increase in heat flow leads to an increase in the surface temperature of the charge T_{Π} by 3...4 times.

At the same time, the time of thermal exposure is $t = 30 \dots 45$ s. At $t \geq 50 \dots 70$ s, there is a sharp increase in T_{Π} (more than 10...15 times).

Actions with critical values of heat flows q_n from external heat sources and their action times t^* are accepted as fire-explosive thermal effects on the surface of pyrotechnic products. In this case, the surface temperature of the charges T_{Π} satisfies the condition: $T_{\Pi} > T_3$, where T_3 is the ignition temperature at which the process of exothermic oxidation of magnesium and aluminium powder particles in the gaseous products of thermal decomposition of the oxidizer begins.

Research of burning speed and development of experimental and statistical models.

On the basis of the conducted experimental studies (Figure 3), it was established that an increase in the heating temperature T_0 from 300 K to 800 K and the external pressure P from 105 Pa to 107 Pa leads to an increase in the burning rate of products by 1.5...2 times. At the same time, an increase in the coefficient of the excess of the

oxidizer α from 0.3 to 2.5, the average particle size of metal fuel powder d_m from 38.5 microns to 385 microns, and the oxidizer d_N from 50 microns to 140 microns reduce its value by 1.4...3, 7 times.

New experimental and statistical models (relative error 3...5%) have been developed to determine the critical values of combustion rates of mixtures under conditions of elevated heating temperatures and external pressures:

$$u(T_0, P) = C_0 + C_1 P + C_2 T_0 + C_3 P^2 + C_4 T_0^2 + C_5 P^3 + C_6 P T_0 + C_7 P T_0^2 + C_8 P^2 T_0 + C_9 P^2 T_0^2 + C_{10} P^3 T_0 + C_{11} P^3 T_0^2, \quad (1)$$

де C_j ($j = \overline{0,11}$) – empirical coefficients that depend on the ratio of components, their dispersion and the nature of the oxidant.

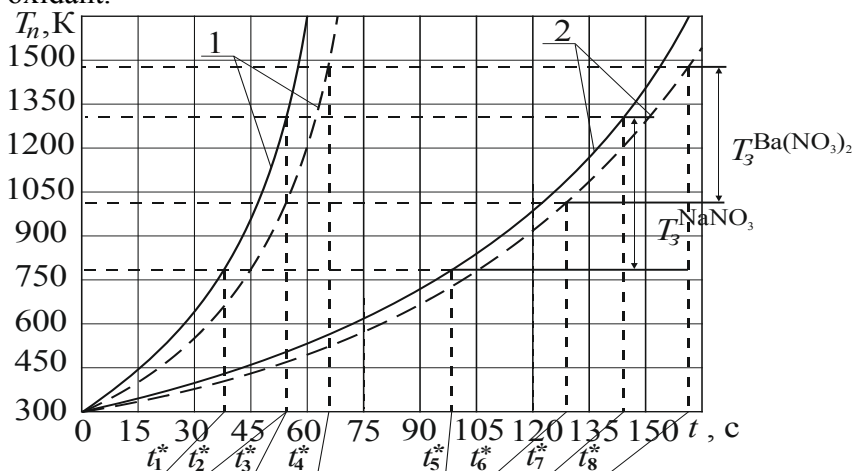


Figure 1 – Dependencies of the temperature of the surface of the products in the form of a flat layer on the external heat flow q_n and its action time t :

1 – $q_n = 2,9 \cdot 10^6 \text{ W/m}^2$; 2 – $q_n = 1,7 \cdot 10^5 \text{ W/m}^2$; – AMA mixture + NaNO_3 ; – AMA mixture + $\text{Ba(NO}_3)_2$;
 $T_b^{\text{NaNO}_3}$, $T_b^{\text{Ba(NO}_3)_2}$ – ignition temperature of AMA particles in decomposition products NaNO_3 and $\text{Ba(NO}_3)_2$

Developed: summarized by the authors

It follows from Figure 1, 2 that at certain critical values of the parameters of external thermal actions q_n and t_j^* ($j = \overline{1,16}$) the surface temperature of the charges of pyrotechnic products begin to exceed the temperature ignition of T_b particles of AMA in decomposition products of oxidants. This leads to their rapid ignition (within $3 \cdot 10^{-3}$... $5 \cdot 10^{-3}$ s) and the rapid development of the burning process of pyrotechnic products under conditions of elevated heating temperatures and external pressures. At the same time, for a more

accurate determination of the q_n and t_j^* parameters, the ranges of T_b changes were obtained depending on the considered technological parameters ($\alpha = 0.3 \dots 2.5$; $d_m = 38.5 \dots 385$ microns; $d_N = 50 \dots 140$ microns) and parameters of the external environment ($T_0 = 300 \dots 800$ K; $P = 105 \dots 107$ Pa):

$$T_b^{\text{KNO}_3} = 800 \dots 1370 \text{ K};$$

$$T_b^{\text{Sr(NO}_3)_2} = 950 \dots 1460 \text{ K};$$

$$T_b^{\text{Ba(NO}_3)_2} = 1070 \dots 1490 \text{ K}.$$

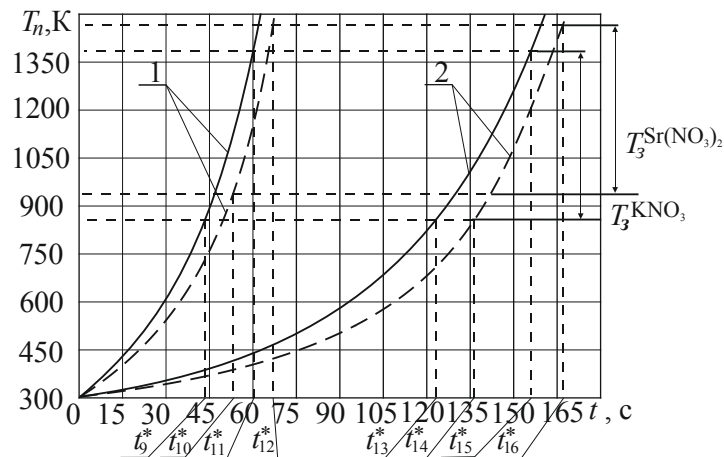


Figure 2 – Dependencies of the temperature of the surface of products in the form of a cylindrical layer on the external heat flow q_n and its action time t : 1 – $q_n = 2,9 \cdot 10^6 \text{ W/m}^2$; 2 – $q_n = 1,7 \cdot 10^5 \text{ W/m}^2$; – AMA mixture + KNO_3 ; – AMA mixture + $\text{Sr}(\text{NO}_3)_2$; $T_3^{\text{KNO}_3}$, $T_3^{\text{Sr}(\text{NO}_3)_2}$ – ignition temperature of AMA particles in decomposition products KNO_3 and $\text{Sr}(\text{NO}_3)_2$

Developed: summarized by the authors

From the data presented in Figure 3, it follows that with an increase in the content of nitrate-containing oxidant (NaNO_3 , $\text{Ba}(\text{NO}_3)_2$, $\text{Sr}(\text{NO}_3)_2$) in pyrotechnic products, the burning rate of the mixture decreases. This indicates that by adjusting these technological parameters at the stage of manufacturing charges of pyrotechnic products, it is possible to increase the stability of the development of their burning process.

The obtained experimental-statistical models (1) make it possible to comprehensively assess the impact of technological parameters on the critical values of the speed of development of burning charges of pyrotechnic products in conditions of elevated heating temperatures and external

pressures in dialogue mode and in real time with the help of computer support.

In conclusion, it should be noted that on the basis of the developed mathematical and experimental-statistical models, it is possible to develop a scientifically based method for determining the critical ranges of changes in the parameters of external thermal effects on the charges of pyrotechnic products and the development rates of their burning process in these conditions. Based on this method, controls and technological recommendations can be developed that increase the fire safety of pyrotechnic products based on mixtures of magnesium, aluminium and metal oxide powders that are manufactured.

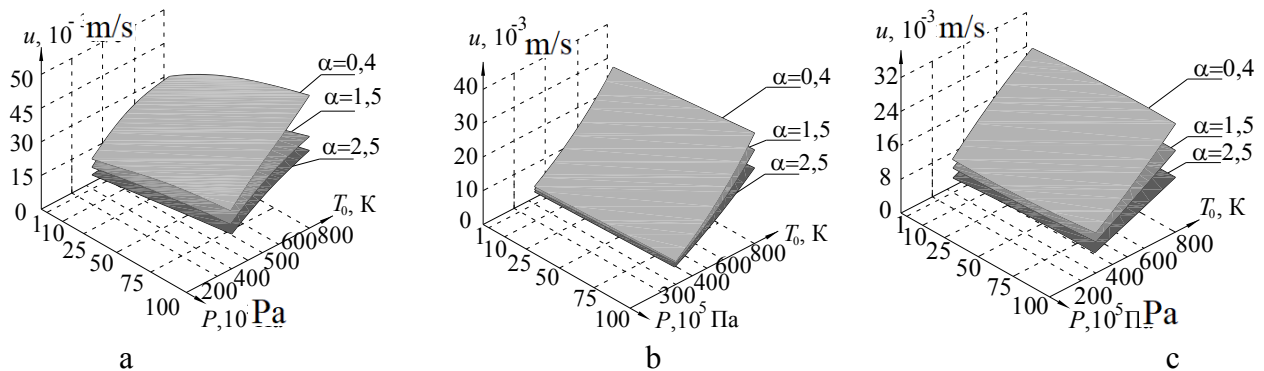


Figure 3 - Dependence of the burning rate of products on the heating temperature and external pressure for equal values of the oxidant excess coefficient ($d_m = 35.8$ microns, $d_N = 140$ microns): a) – AMA mixture + NaNO_3 ; b) – AMA mixture + $\text{Ba}(\text{NO}_3)_2$; c) AMA mixture + $\text{Sr}(\text{NO}_3)_2$

Developed: summarized by the authors

Conclusions and directions for further research. Mathematical models of external heating of charges of pyrotechnic products based on mixtures of AMA powders were developed by taking into account different geometric shapes (flat and cylindrical layers). The temperature dependence of the thermophysical properties of mixtures is also taken into account. The established allows to more accurately determine the critical values of heat flows and the duration of their influence (the relative error has been reduced to 5...7% instead of 10...12% in existing models). This allows you to prevent premature activation and fire-hazardous destruction of products.

1. New experimental data were obtained on the dependence of the combustion rate of mixtures on the technological parameters (coefficient of excess oxidizer α , dispersion of metal fuel d_m and oxidizer d_N) and external conditions (heating temperature T_0 and external pressure P). It was found that increasing α from 0.3 to 2.5, d_m from 35.8 microns to 385 microns,

and d_N from 50 microns to 140 microns reduce its value by 1.4...3.7 times.

2. For the first time, experimental and statistical models were developed to determine (with a relative error of 3...5%) the critical ranges of change in the burning rate of mixtures under conditions of elevated heating temperatures (up to 800 K) and external pressures (up to 107 Pa) depending on the ranges of changes in technological parameters: $\alpha = 0.3...2.5$, $d_m = 35.8...385$ microns and $d_N = 50...140$ microns. Exceeding these ranges leads to explosive development of combustion under conditions of external thermal effects and fire-hazardous destruction of products.

The results of the obtained calculations, the obtained new experimental data and the developed experimental and statistical models for determining the critical ranges of change in the burning rate of mixtures under conditions of elevated heating temperatures and external pressures for various values of the technological parameters of the data are planned to be used in the future to create an appropriate database for pyrotechnic products.

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ПОПЕРЕДЖЕННЯ ПЕРЕДЧАСНОГО СПРАЦЬОВУВАННЯ ПІРОТЕХНІЧНИХ ВИРОБІВ НА ОСНОВІ СУМІШЕЙ З ПОРОШКІВ МАГНІЮ, АЛЮМІНІЮ ТА ОКСИДІВ МЕТАЛІВ В УМОВАХ ЗОВНІШНІХ ТЕРМІЧНИХ ДІЙ

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КЛЮЧОВІ СЛОВА:

пожежна безпека,
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АННОТАЦІЯ

Для організації процесу горіння багатокомпонентних піротехнічних сумішей широко використовуються піротехнічні вироби на основі ущільнених двокомпонентних сумішей з порошків алюмінієво-магнієвих сплавів та нітратовмісних окиснювачів (нітратів натрію, калію тощо). Уточнено математичні моделі зовнішнього нагріву зарядів піротехнічних виробів на основі сумішей з порошків магнію, алюмінію та оксидів металів через урахування температурних залежностей їх теплофізичних властивостей, що дало змогу більш точно визначати критичні значення теплових потоків та тривалостей їх впливу. Отримано нові експериментальні дані та розроблено експериментальні статистичні моделі для визначення критичних діапазонів швидкостей горіння сумішей за підвищених температур нагрівання (до 800 K) і зовнішнього тиску (до 10^7 Па) для різних значень технологічних параметрів (коефіцієнт надлишку окислювача α ; середній розмір частинок порошкового металевих палива d_m і окисника d_N). Визначено, що перевищення критичних діапазонів технологічних параметрів призводить до нестійкого вибухонебезпечного розвитку їх горіння та пожежонебезпечного руйнування піротехнічних виробів на основі сумішей магнію, алюмінію та оксидів металів після передчасного займання сумішей в умовах зовнішніх термічних дій. На основі розроблених математичних та експериментально-статистичних моделей можна розробити науково-обґрунтований метод визначення критичних діапазонів зміни параметрів зовнішніх теплових дій на заряди піротехнічних виробів та швидкостей розвитку їх горіння в них. умови. На підґрунті цього методу можна розробити засоби контролю та технологічні рекомендації, що підвищують пожежну безпеку виготовлених піротехнічних виробів на основі сумішей оксидів магнію, алюмінію та металів. Результати розрахунків, нові експериментальні дані та розроблені експериментальні статистичні моделі для визначення критичних діапазонів швидкості горіння сумішей за підвищених температур і зовнішнього тиску для різних значень технологічних параметрів даних будуть використані для створення відповідної бази даних піротехнічних виробів.