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APPLICATION OF THERMODYNAMIC ANALYSIS METHODS IN DETERMINING THE TEMPERATURE OF COMBUSTION PRODUCTS IN THE COMBUSTION PROCESS OF PYROTECHNIC MIXTURES WITH ADDITIVES OF ORGANIC SUBSTANCES

Pyrotechnic products of general industrial purpose (lighting products, pyrotechnic infrared emitters, etc.) are widely used for spectacular events, light and noise effects for cinema and television.

To increase the ignition efficiency and the stable development of the combustion of the main charges of multi-component pyrotechnic mixtures, which give special effects (light, color-flame, thermal, etc.), which are equipped with many general industrial pyrotechnic products, as well as some pyrotechnic products for special purposes (elements of rocket and space techniques, means of targeting and monitoring ground and air targets, etc.) are widely used, as well as for some explosive ammunition [2 - 5], instead of traditional sources of ignition (electric detonator, fire-conducting rope, electric igniter, fuse-match, etc.) nitrate-metal, the basis of which are compacted mixtures of metal powders, nitrate-containing oxidizers and technological additives of organic substances.

Therefore, the purpose of this work is to determine the temperature of combustion products and the content of high-temperature condensate in them for mixtures of metal fuel powders (aluminum, magnesium, zirconium), nitrate-containing oxidizer (sodium nitrate) and organic substance additives (paraffin, stearin, naphthalene, anthracene) using known methods of thermodynamic analysis

As a result of studies of the temperature and composition of combustion products of multicomponent pyrotechnic mixtures made from components of nitrate-metal ignition sources, the following regularities were established the qualitative and quantitative composition of the products of combustion of mixtures depends most significantly on α and P, while the characteristic ranges of their changes correspond to a certain composition of the products of combustion of mixtures, while the amount of organic additives most strongly affects the content of high-temperature condensate in the products of combustion of mixtures.

Key words: *pyrotechnic mixture, fire safety, thermodynamic analysis, pyrotechnic products, combustion processes, temperature of combustion products.*

Formulation of the problem. Nowadays, pyrotechnic products of general industrial purpose (lighting products, pyrotechnic infrared emitters, etc.) are widely used for spectacular events, light and noise effects for cinema and television [1-9].

To increase the ignition efficiency and the stable development of the combustion of the main charges of multi-component pyrotechnic mixtures, which give special effects (light, color-flame, thermal, etc.), which are equipped with many general industrial pyrotechnic products, as well as some pyrotechnic products for special purposes (elements of rocket and space techniques, means of targeting and monitoring ground and air targets, etc.) are widely used, as well as for some explosive ammunition [2 - 5], instead of traditional sources of ignition (electric detonator, fire-conducting rope, electric igniter, fuse-match, etc.) nitrate-metal, the basis of which are compacted mixtures of metal powders, nitrate-containing oxidizers and technological additives of organic substances. This is due to the fact that the mixtures used in ignition sources form combustion products with high temperatures (up to 3000...4000 K) and the relative content of high-temperature condensate (up to 0.5...0.7), which generate heat fluxes on the surface of the main charges of order products $2.1 \cdot 10^6 ... 8.4 \cdot 10^6$ W/m^2, which ensures, as numerous field tests show, their reliable operation. Therefore, during the development of pyrotechnic products, it is necessary to control the high temperature of the products of combustion of the specified multicomponent mixtures, as well as the high content of high-temperature condensate in them, which ensure the failure-free operation of the main charges of pyrotechnic products under the standard conditions of their use.

Analysis of recent achievements and publications. The high burning temperatures of pyrotechnic mixtures and their chemical activity make it difficult to directly measure the early mentioned characteristics. Therefore, methods of thermodynamic analysis are widely used to determine the possible ranges of temperature changes and the composition of combustion products of mixtures [1-12].

Highlighting previously unresolved parts of the general problem, to which the article is devoted. *As for the considered multi-component pyrotechnic mixtures with organic additives, nowadays there are no data for such mixtures.*

Setting the problem and solving it. Therefore, the purpose of this work is to determine the temperature of combustion products and the content of high-temperature condensate in them for mixtures of metal fuel powders (aluminum, magnesium, zirconium), nitrate-containing oxidizer (sodium nitrate) and organic substance additives (paraffin, stearin, naphthalene, anthracene) using known methods of thermodynamic analysis

Presentation of the main material of the study with a full justification of the obtained results. The results of calculations of the temperature of the combustion products of the considered mixtures (T_c, K) and their relative content of high-temperature condensate (g_K^{Me}) are presented in Fig. 1 – 5. In this case, the following general regularities of the influence of the coefficient of excess oxidant in the mixture (α), the relative content of the additive of organic matter (ε) and external pressure (P, Pa) on the indicated thermodynamic parameters for different natures of metallic fuel, oxidant and organic matter are considered.

Temperature of combustion products.

From the results of the calculations (Figs. 1 – 3), it follows that for all mixtures the dependence $T_c(\alpha)$ has a maximum $T_{c\ max}$ that is close to $\alpha = 1.0$. An increase in external pressure from $P = 10^5$ Pa to $P = 10^7$ Pa leads only to an increase in the combustion temperature; at the same time, the position of the maximum on the curve $T_c(\alpha)$ does not change. The effect of the addition of organic matter, regardless of its nature, leads only to a decrease in the value of T_c without changing the nature of the dependence $T_c(\alpha)$.

Relative content of high-temperature condensate.

Taking into account these calculations (Figs. 4-6) it is seen that the dependences for each mixture have a complex character with minimums and maximums. At the same time, an increase in external pressure in the range of $10^5 ... 10^7$ Pa, in contrast to the dependence of $T_c(\alpha)$, leads not only to an increase in the value g_K (for example, the positions of the minimums and maximums on the curves change $g_K^{Me}(\alpha)$).

An increase in the value of the addition of organic matter in the mixture leads to a decrease in the value g_K for the entire studied range of changes in external pressure.

Comparing the results of thermodynamic calculations with the obtained experimental data shows that the difference between them does not exceed 8...10%, which allows them to be used as engineering calculation methods at the stages of designing and manufacturing ignition sources.

To check the adequacy of the obtained results, the temperature of combustion products was selectively measured using special tungsten-rhenium thermocouples [4, 6], as well as the relative content of high-temperature condensate in them using known methods of X-ray structural analysis [16].

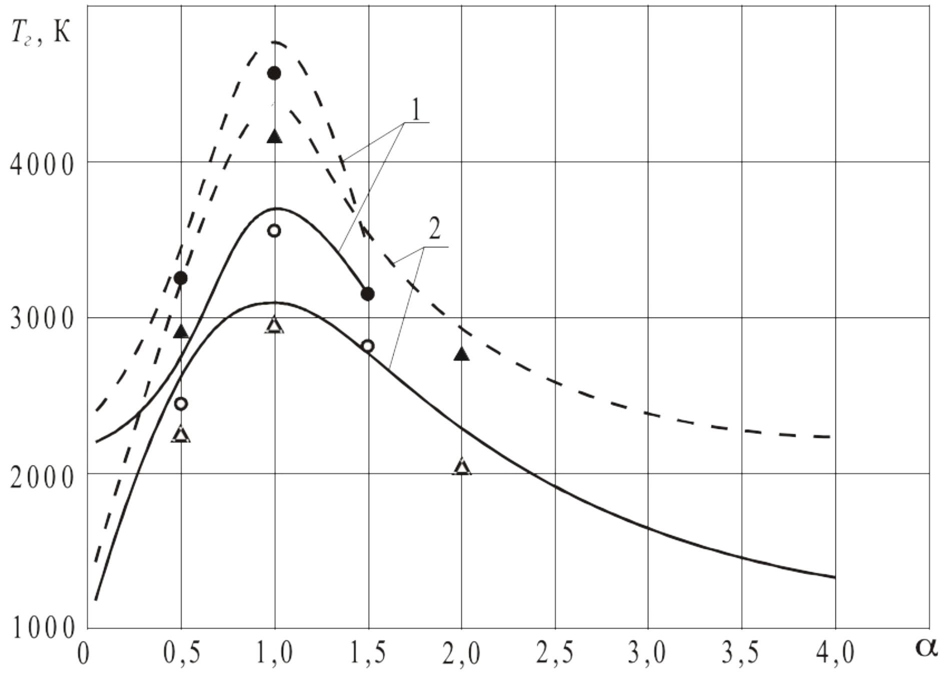

Figure 1 – Curve of the dependence of the temperature of the combustion products of a multicomponent pyrotechnic mixture based on aluminum with sodium nitrate (1) and on the basis of magnesium with sodium nitrate (2) on the coefficient of excess oxidant: ———— – $P = 10^5$ Pa ; – – – – – – – $P = 10^7$ Pa.

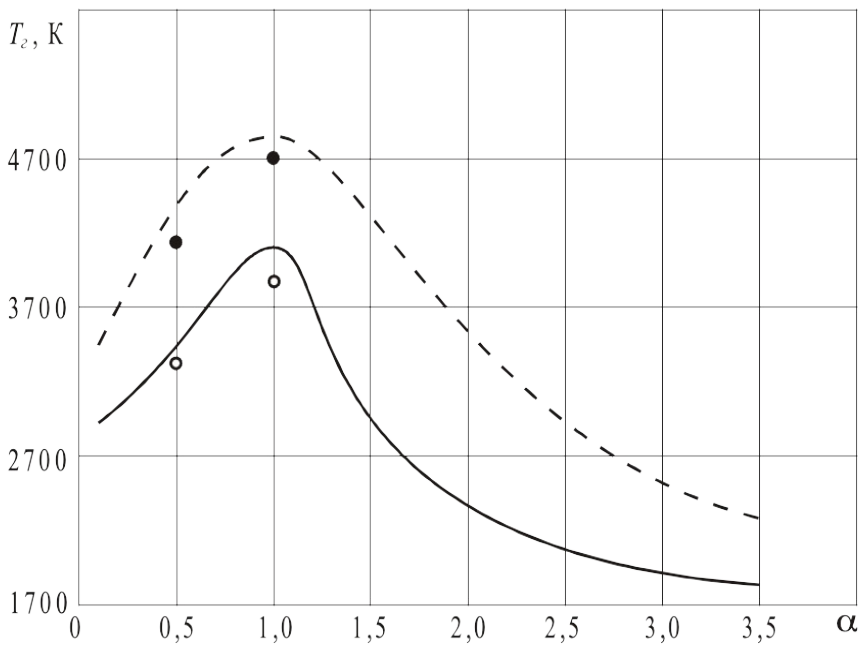

Figure 2 – Curve of dependence of the temperature of the combustion products of a multicomponent pyrotechnic mixture based on zirconium with the addition of an organic substance on the coefficient of excess oxidant: ———— – $P = 10^5$ Pa; – – – – – – – $P = 10^7$ Pa.

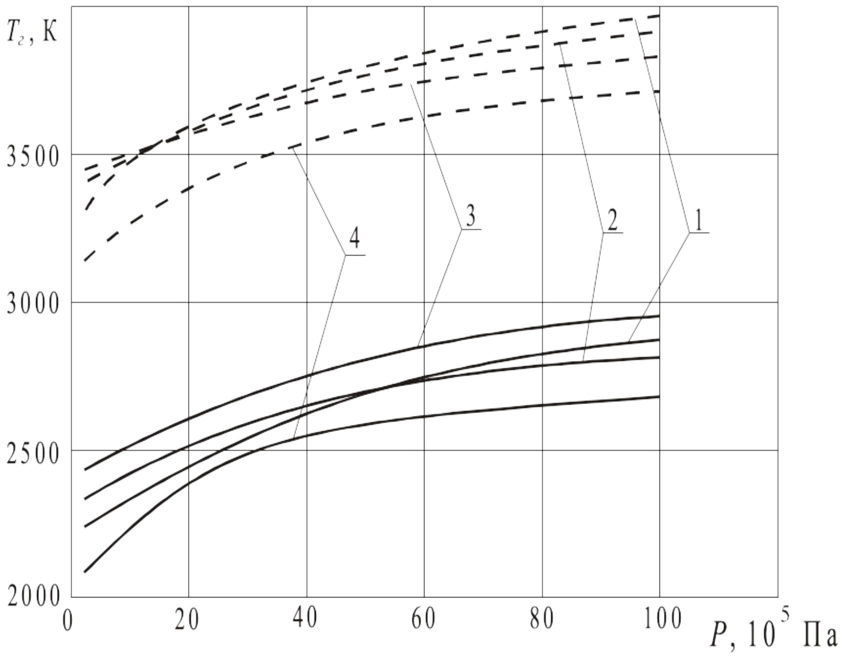

Figure 3 – Curve of temperature dependence of the combustion products of a multicomponent pyrotechnic mixture based on aluminum with additives of organic substances: naphthalene (1), stearin (2), anthracene (3) and paraffin (4) on external pressure (α = 1,0): ————— – ε = 0,20; – – – – – – – ε = 0,05.

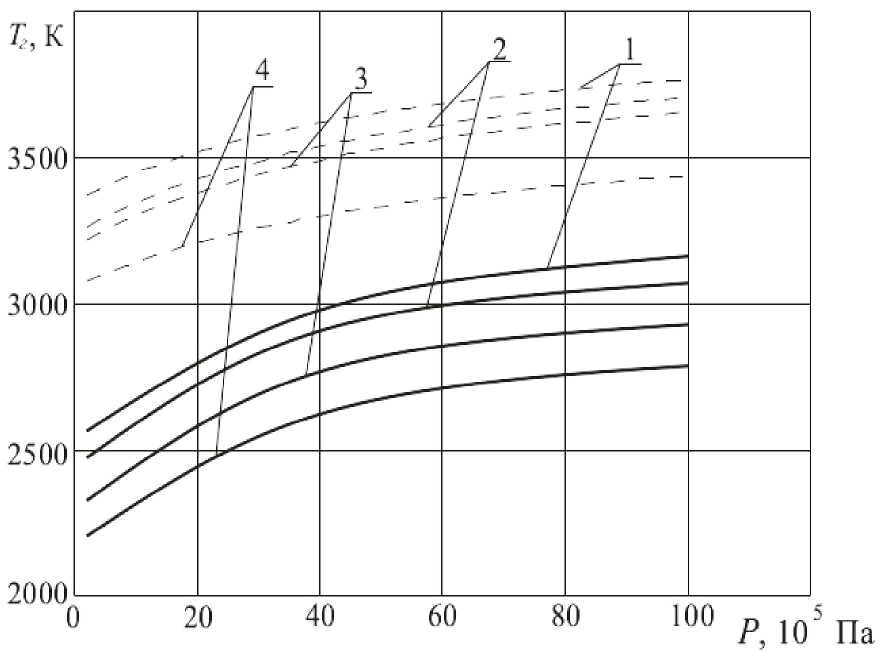

Figure 4 – Curve of dependence of the temperature of the combustion products of a multicomponent pyrotechnic mixture based on zirconium on the influence of additives of organic substances anthracene (1), naphthalene (2), stearin (3) and paraffin (4) on external pressure (α = 1,0): ————— – ε = 0,20; – – – – – – – ε = 0,05.

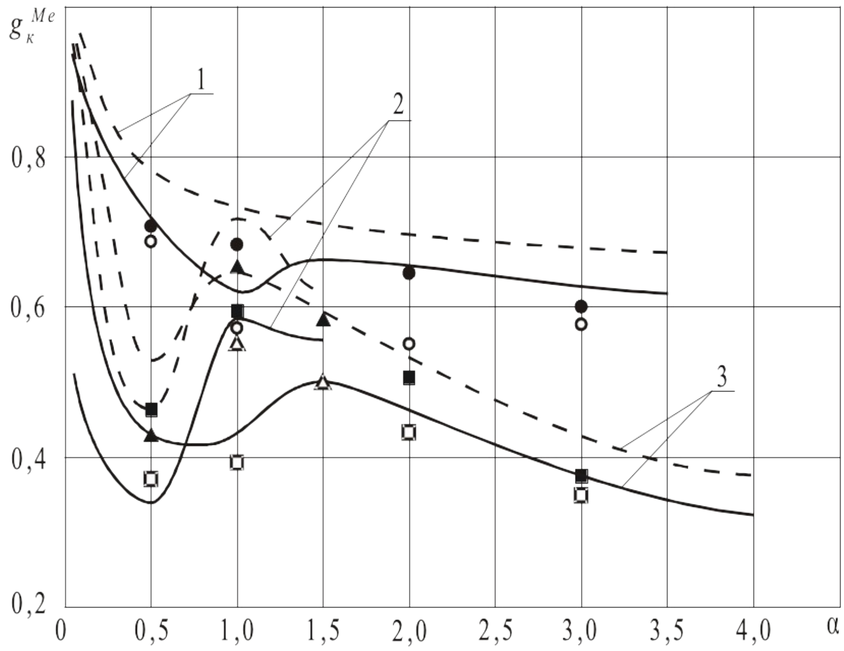

Figure 5 – Curve of the dependence of the relative content of high-temperature condensate in the combustion products of mixtures of sodium nitrate with zirconium (1), aluminum (2) and magnesium (3) on the coefficient of excess oxidant under the influence of external pressure: —————– $P = 10^5$ Pa; – – – – – – – – $P = 10^7$ Pa.

Conclusions. As a result of studies of the temperature and composition of combustion products of multicomponent pyrotechnic mixtures made from components of nitrate-metal ignition sources, the following regularities were established for the first time.

1. The temperature of the combustion products T_c most significantly depends on the coefficient of excess of the oxidizer and α has maximum values $T_{c\ max}$ = 3400...4760 K at = 0.97...1.05 and pressures $P = 10^5...10^7$ Pa.

2. According to the degree of strengthening of the effect on T_c, metallic fuels are located in the series Mg < Zr < Al, while the increase in external pressure leads only to an increase in T_c values without changing the nature of the dependences $T_c(\alpha)$.

3. The introduction of organic substance additives into the mixture leads to a decrease in T_c values, and also has an ambiguous effect on the nature of the dependence $T_c(\alpha)$: for paraffin additives $\alpha_{Tc\ max}$, the position on the curve $T_c(\alpha)$ does not change, but for stearin, naphthalene, and anthracene additives, it shifts towards the excess of metallic fuel.

4. The qualitative and quantitative composition of the products of combustion of mixtures depends most significantly on α and P, while the characteristic ranges of their changes correspond to a certain composition of the products of combustion of mixtures, while the amount of organic additives most strongly affects the content of high-temperature condensate in the products of combustion of mixtures.

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ЗАСТОСУВАННЯ МЕТОДІВ ТЕРМОДИНАМІЧНОГО АНАЛІЗУ ПРИ ВИЗНАЧЕННІ ТЕМПЕРАТУРИ ПРОДУКТІВ ЗГОРЯННЯ В ПРОЦЕСІ ГОРІННЯ ПІРОТЕХНІЧНИХ СУМІШЕЙ З ДОБАВКАМИ ОРГАНІЧНИХ РЕЧОВИН

Піротехнічні вироби загальнопромислового призначення (освітлювальні вироби, піротехнічні ІЧ-випромінювачі тощо) широко використовуються для проведення видовищних заходів, світлових та шумових ефектів для кіно та телебачення.

Для підвищення ефективності загорання та стабільного розвитку горіння основних зарядів багатокомпонентних піротехнічних сумішей, що дають спеціальні ефекти (світловий, кольорово-полум'яний, тепловий тощо), якими споряджаються багато загальнопромислових піротехнічних виробів, а також деякі піротехнічні вироби спеціального призначення (елементи ракетно-космічної техніки, засоби наведення та спостерігання за наземними та повітряними цілями тощо) широко використовуються, також як й для деяких вибухових боєприпасів [2 - 5], замість традиційних джерел запалювання (електродетонатор, вогнепровідна мотузка, електроспалахувач, запал-сірник тощо) нітратно-металеві, основою яких є ущільнені суміші з порошків металів, нітратовмісних окиснювачів та технологічних добавок органічних речовин.

Метою цієї роботи є визначення температури продуктів згорання та вмісту в них високотемпературного конденсату для сумішей порошків металевих пальних (алюмінію, магнію, цирконію), нітратовмісного окиснювача (нітрату натрію) та добавок органічних речовин (парафін, стеарин, нафталін, антрацен) за допомогою відомих методів термодинамічного аналізу

В результаті проведених досліджень температури та складу продуктів згорання багатокомпонентних піротехнічних сумішей з компонентів нітратно-металевих джерел запалювання встановлено, що якісний та кількісний склад продуктів згорання сумішей найбільш суттєво залежить від α та Р, при цьому характерним діапазонам їх зміни відповідає певний склад продуктів згорання сумішей, при цьому найбільш сильно впливає на вміст високотемпературного конденсату в продуктах згорання сумішей величина органічної добавки.

Ключові слова: *піротехнічна суміш, пожежна безпека, термодинамічний аналіз, піротехнічні вироби, процеси горіння, температура продуктів згоряння.*