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On probabilistic-physical and entropy approaches to combustion processes and determination of fire hazard

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Introduction. The article provides an overview of the existing approaches to solving the problem of combustion of substances and materials, for their adequacy in determining their fire hazard of products and objects. The relevance of the work is due to the need to move from latent forms in determining the fire hazard of materials and products made from them (degrees of fire resistance, flammability groups, groups of the effectiveness of fire retardant coatings, etc.) to analytical forms describing the processes in the combustion theory.

Problem statement. The task of the research is to determine the relationship between the theory of combustion of substances and materials and to assess their fire hazard in natural and man-made systems.

Theoretical part. The system analysis of solutions to the combustion theory problems is performed. Its results became the basis of probabilistic-physical and entropy approaches, as well as proposals for changing standards designed to provide protection from fires.

Conclusions. The results of the study showed the need to revise empirical approaches in assessing the fire hazard of materials and products made from them, which includes using thermoanalytic and acoustic methods and means.

Keywords: combustion theory, fire hazard of substances and materials, probability of fire, entropy, baro-electro-thermo-acoustic analysis, vector-function of the life cycle of materials, fire safety of objects

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Introduction. According to the Center for Fire Statistics of the International Association of Fire and Rescue Services, up to 4.5 million fires are registered annually in the world, in which up to 60 thousand people die. The leader is the United States with an annual rate of 1.3 million fires. As for Russia, the maximum number of fires was recorded in 1996 — almost 300 thousand. [1][1].

According to the author of the presented work, such a situation has arisen and persists because fundamental science, having once solved the main combustion problems, has not bothered with applied tasks. Their unsatisfactory solutions, in addition to socio-economic losses, led to a steady increase in the number of fires and damage from them. The dynamics may not be so obvious if you focus only on government statistics that compare each year with the previous one [1][2]. A more accurate picture is given by the trend line. Figure 1 shows that it is ascending [3] [2]. It should be noted that the data from the end of the last century have been visualized and supplemented with information on electricity consumption. The correlation is obvious. Moreover, it proves the dependence of fires and related losses on the consumption of electricity by technosphere objects, i.e., on changes in the specific "power supply capacity" of the population and facilities.

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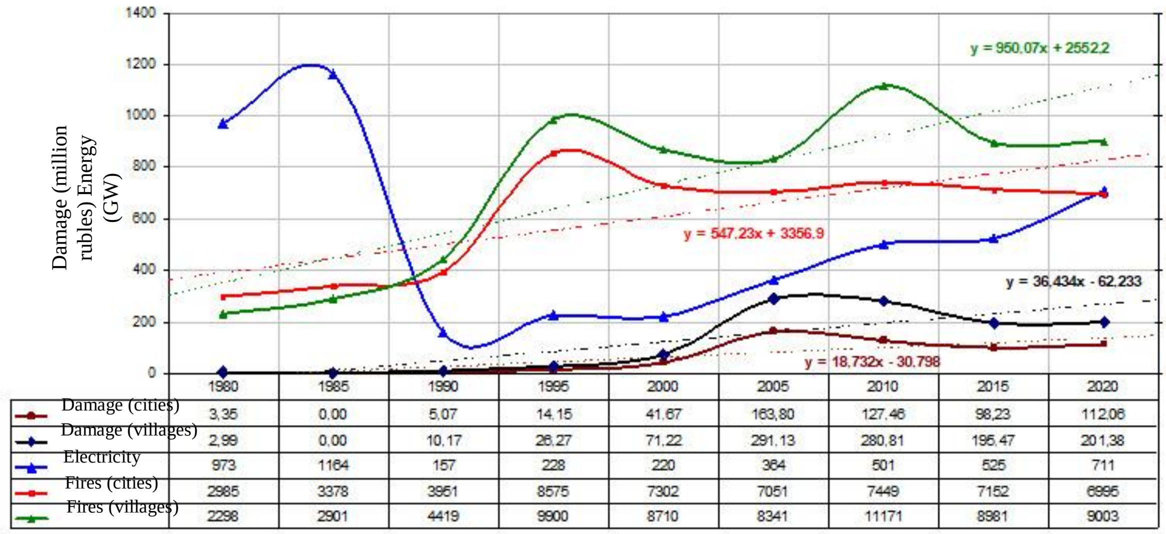
[1] Fires and fire safety. EMERCOM of Russia. VNIIPO. Available from: http://www.vniipo.ru/institut/informatsionnye-sistemy-reestry-bazy-i-banki-danny/federalnyy-bank-dannykh-pozhary/ (accessed: 18.09.2021).

[2] Idem.

[3] Belozerov V. V. Automated testing system of materials of electrical and electronic industry with control of their fire hazard. Author's thesis. Moscow, 2008. 153 p.



	1980	1985	1990	1995	2000	2005	2010	2015	2020
Damage (cities)	3,35	0,00	5,07	14,15	41,67	163,80	127,46	98,23	112,06
Damage (villages)	2,99	0,00	10,17	26,27	71,22	291,13	280,81	195,47	201,38
Electricity	973	1164	157	228	220	364	501	525	711
Fires (cities)	2985	3378	3951	8575	7302	7051	7449	7152	6995
Fires (villages)	2298	2901	4419	9900	8710	8341	11171	8981	9003

Fig. 1. Fires, their damage and energy consumption in the south of Russia (Rostov region, Krasnodar and Stavropol territories)

At the same time, the main causes of social losses from fires (Fig. 2) are combustion products (69.36 %) and high temperature (20.26 %) with concomitant factors (lack of oxygen — 3.93 % and exacerbation of diseases — 1.79%)[4] [2].

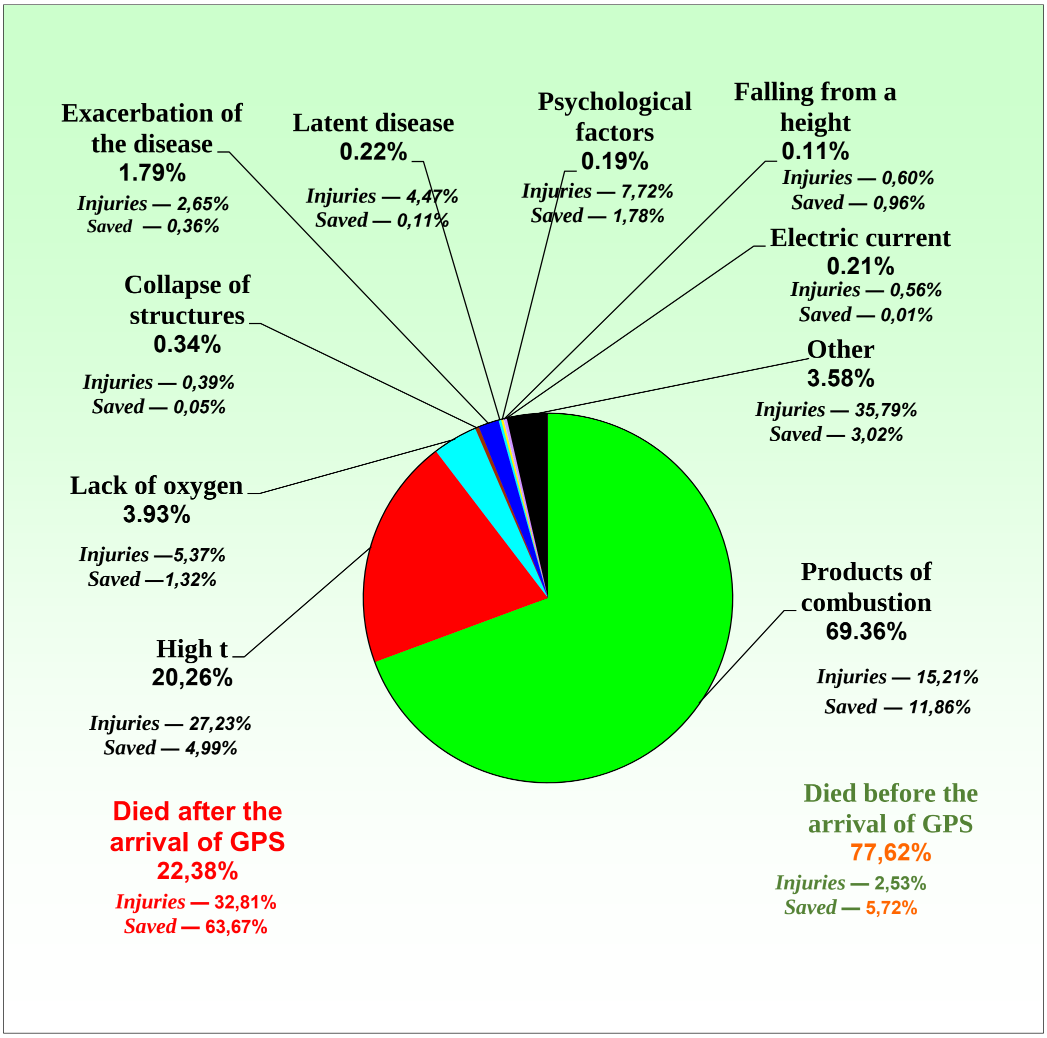


Fig. 2. Statistical data on the causes of deaths and injuries in fires in the south of Russia (Rostov region, Krasnodar and Stavropol territories)

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[4] Belozerov V. V. Op. cit.

According to the results of statistical analysis (Fig. 3), the main sources of fires are appliances and household items (including electric, gas appliances and stoves). They account for more than 70% of incidents. Approximately 26 % of cases involve careless handling of fire. 40 % of fires occur due to electrical and gas engineering reasons. They are associated with about 50% of direct material losses and damage to areas [5] [2].

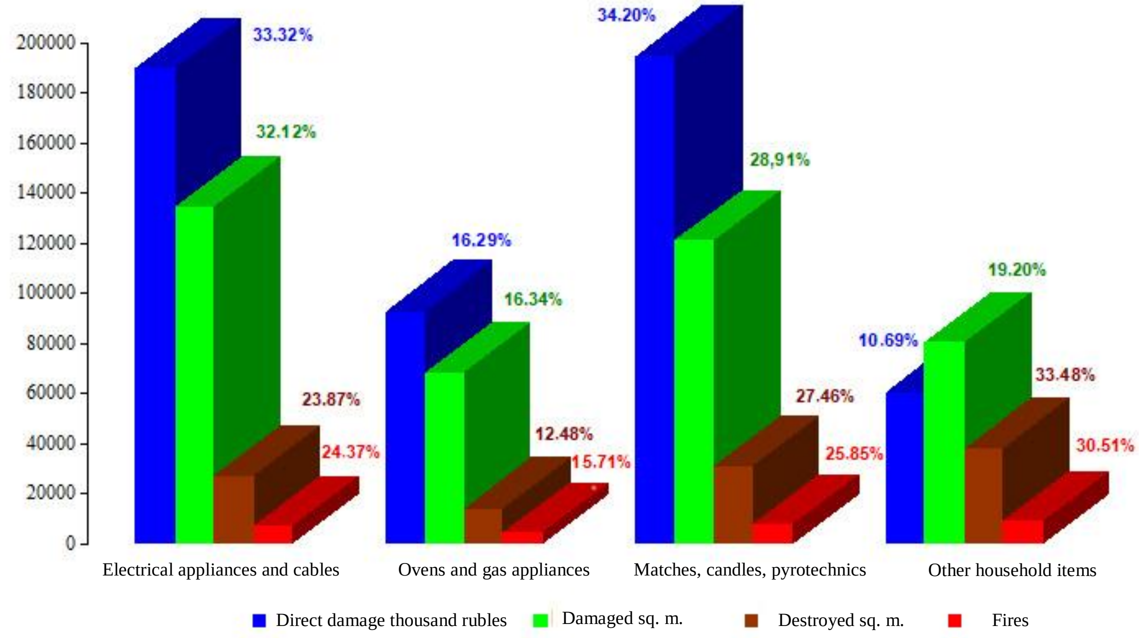

Fig. 3. Statistics on sources of fires and losses from them in the south of Russia (Rostov region, Krasnodar and Stavropol territories), shares in % for each group of sources

This situation has arisen because the firefighters themselves are engaged in working out fire safety issues. For example, specialists in this industry have created a "Technical Regulation on fire safety requirements", relevant standards and norms [2][6, 7].

Theoretical Part. The assessment of socio-economic losses from fires according to GOST 12.1.004 (the probability of fires is not higher than 10^{-6}, the safety of the population is not lower than 0.999999) gives the level of the "permissible" number of annual number of people dying in fires — no more than 146 people (for the 146 million population of Russia)[8].

Over the past 50 years, the annual losses in the country from fires have been more than 100 times higher than permissible. This proves the fallacy of methods and means for determining the fire hazard of man-made and natural systems, and hence the inadequacy of the existing methods and technical means of their fire protection[9] [2].

Moreover, during the development of the "Technical Regulations on fire safety requirements" and "Fire Safety Rules"[10, 11] the Ministry of Emergency Situations of Russia did not involve fundamental science in solving safety problems. Instead, the agency introduced new latent fire risk indicators. Two observations should be made regarding this approach. First. There is no satisfactory scientific theoretical justification for latent fire risk indicators yet, despite the attempts made [3]. Second. Even 10 years after the innovations of the Ministry of Emergency Situations, the situation has not practically changed, and this is confirmed by statistics[12] [2].

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[5] Belozerov V. V. Op. cit.

[6] Technical Regulations on fire safety requirements. Federal Law No. 123-FZ of 22.07.2008. State Duma. Federation Council. ConsultantPlus. Available from: http://www.consultant.ru/ (accessed: 19.09.2021).

[7] Rules of the fire-fighting regime in the Russian Federation. Decree of the Government of the Russian Federation No. 390 of 25.04.2012 (ed. of 24.12.2018) "On the fire-fighting regime". ConsultantPlus. Available from: http://www.consultant.ru/document/cons_doc_LAW_129263/ (accessed: 19.09.2021).

[8] GOST 12.1.004 Fire safety. General requirements. Moscow: Publishing House of Standards, 1992. 77 p.

[9] Belozerov V. V. Op. cit.

[10] Technical regulations on fire safety requirements.

[11] Rules of fire protection regime in the Russian Federation.

[12] Fires and fire safety.

Another domestic standard — GOST 12.1.044 "Fire and explosion hazard of substances and materials" is a copy of international standards and has long required revision [13]. The document should be updated in terms of the use of thermoanalytic methods (thermogravimetry, differential scanning calorimetry, etc.) to determine the physico-chemical and thermodynamic characteristics of substances and materials. This will make it possible to abandon latent parameters (flammability groups, degrees of fire resistance, toxicity, etc.) [14] [4].

So, the reduction of losses from fires involves taking into account the thermodynamic characteristics of substances, materials and products made of them under operating conditions [5]. In addition, it is necessary to know the features of technical means, buildings, structures and other objects in general, surrounded by natural systems [4]. This approach will eliminate the possibility of an increase in entropy in each of the life support systems and subsystems, including social entropy caused by the human factor [4, 6].

From the above, it can be concluded that the main safety problems of man-made and natural systems are not being solved because international and national standards in this area are outdated and harmful. The methods and means used by them to determine the fire and explosion hazard and combustibility of substances and materials do not allow us to adequately assess their danger, and hence the danger of products made from them, equipment, transport and energy facilities and systems, buildings and structures[15] [2, 4].

So far, these main problems have not been solved. Therefore, the methods and means of fire protection are being developed and applied, which are not adequate to the real fire danger of objects and do not perform their functions, that is, they do not provide the safety parameters required by GOST 12.1.004[16].

It is appropriate to note that the head research organization of the Ministry of Emergency Situations of Russia (VNIIPO) has been conducting research on the fire hazard of substances and materials by thermal analysis methods for more than 10 years[17]. There are more than 3 thousand substances and materials in the data bank. In 2003, Belarus introduced into force some of its state standards of the characteristics of building materials determined by the methods and means of thermal analysis. In this regard, it can be concluded that there is a promising expansion of the use of thermoanalytical devices and physico-chemical parameters of materials instead of indirect methods and latent variables[18, 19].

From the point of view of fundamental and applied sciences, the most effective is the study of substances and materials at extreme pressures and temperatures, in vacuum, etc. So, for example, methods of thermal analysis: thermogravimetry, thermodilatometry, differential scanning calorimetry and others allow you to determine many important factors that can be divided into four groups. Firstly, these are the parameters of crystallization and melting points, sublimation and ignition, and phase transitions. Secondly, thermodynamic characteristics of materials: heat capacity, enthalpy, compression, expansion coefficients, etc. Thirdly, similarity criteria: thermal conductivity and Poisson's coefficients, Young's modules, Bio numbers, etc. Fourth, some "fire" indicators: heat of melting and combustion, oxygen index, etc. However, due to the difficulties of metrological certification of thermal analysis installations, the data obtained have significant errors and are mainly used for qualitative assessments [20, 21, 22].

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[13] GOST 12.1.044 Fire and explosion hazard of substances and materials. Nomenclature of indices and methods of their determination. Moscow: Publishing House of Standards, 1990. 143 p.

[14] Belozerov V. V. Op. cit.

[15] Belozerov V. V. Op. cit.

[16] Belozerov V. V. Methods, models and means of automation of technosphere safety management. Author's thesis. Moscow, 2013. 422 p.

[17] Molchadskiy O. I., Smirnov N. V., Duderov N. G. Otsenka teplofizicheskikh kharakteristik i prognoz pozharnoy opasnosti stroitel'nykh materialov s pomoshch'yu metodov termicheskogo analiza. Problemy goreniya i tusheniya pozharov na rubezhe vekov: sb. mat-lov XV nauch.-prakt. konf. Ch. 1. Moscow : VNIIPO, 1999. p. 170–172.

[18] STB 1333.0-2002. Polymer products for construction. Method for determining durability by activation energy of thermooxidative destruction of polymers. Ministry of Architecture and Construction of the Republic of Belarus. Available from: https://www.studmed.ru/stb-1333-0-2002-izdeliya-polimernye-dlya-stroitelstva-metod-opredeleniya-dolgovechnosti-po-energii-aktivacii-termookislitelnoy-destrukcii-polimernyh-materialov_4ecedd28114.html (accessed: 20.09.2021).

[19] STB 1333.2-2002. Polymer products for construction. Method for determining the durability of polymer pipes for engineering systems. Ministry of Architecture and Construction of the Republic of Belarus. Available from: https://shop.belgiss.by/ru/gosudarstvennye-standarty/stb-1333-2-2002 (accessed: 14.09.2021).

[20] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[21] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[22] Thermal analysis devices. Available from: http://www.netzsch-thermal-analysis.com/ru/produkte/ (accessed: 22.09.2021).

For more than 40 years, fundamental and applied science has been using the acoustic emission (AE) method, based on the registration and analysis of acoustic radiation that occurs when the structure and physico-chemical properties of substances and materials change. The advantage of AE is its non-destructive nature. This is a necessary condition for the study of dissipative processes that characterize the degradation of parameters and "aging" of substances and materials, which makes it possible to predict changes in their structure and properties under operating conditions [7, 8].

As studies have shown [23] [8], AE makes it possible to accurately register some "fire" parameters: the stages of melting, pyrolysis, ignition and combustion. For this purpose, this method should be used synchronously with thermogravimetry and thermodilatometry of the sample. However, bearing in mind the accuracy and reliability of the results, it is worth noting that AE devices and installations have the same metrological difficulties as thermal analysis devices [7, 8].

Therefore, when studying substances and materials in real operating conditions, it is advisable to use a probabilistic-physical approach, as well as a thermodynamic interpretation of degradation processes. This is the most promising direction, including from the point of view of objectification of fire hazard parameters [4–6][24].

To date, several approaches have been adopted in fundamental and applied science to determine the conditions of ignition (self-ignition and ignition) of substances and materials.

The first one was developed by Nobel laureate academician N. N. Semenov. This is the founder of the theory of combustion, who proposed to consider the sources of heat release Arrhenius, and heat removal — Newtonian, provided the same temperature throughout the reacting mas [9]:

$$\frac{E_a}{RT_s^2}\cdot\frac{QV}{\alpha F}\cdot k\cdot\exp\left(-\frac{E_a}{RT_s}\right)\geq\frac{1}{e} \tag{1}$$

where E_a — the activation energy, $J\cdot mole^{-1}$; R — gas constant, 8.3 $J\cdot mole^{-1}\ K^{-1}$; Q — heat effect of reaction, $J\cdot mole^{-1}$; α — heat transfer coefficient, $W\cdot m^{-2}\cdot K^{-1}$; F — surface area, m^2; V — volume of material, m^3; k — pre-exponent; e — base of natural logarithms; T — temperature of auto-ignition of a substance (gas mixture), K.

An alternative to the Semenov criterion (1/e) was the approach developed at the Research Institute for Fire Protection. The self-ignition temperature T was associated by a power function with the surface area of the material F and its volume V [10]:

$$T_{ign}=A_p\cdot\left(\frac{F}{V}\right)^{n_p} \tag{2}$$

Here A_p — the empirical coefficient; $n_p=\frac{E_a/RT_A}{\left(E_a/RT_A+1\right)}$ — the exponent of the power function, where T_A — the ambient temperature. The other designations are the same.

The disadvantage of both methods: when determining the conditions of spontaneous ignition of substances and materials, the heterogeneity of heating of the reacting mass was not taken into account. The remaining shortcomings and errors relate to the accuracy and reliability of parameter determination. They are listed below[25, 26] [10].

— The Semenov criterion (1/e) should not take a value that is the reverse of the base of natural logarithms. It should be calculated, for example, as the ratio of the derivatives of the heat release rates.

— The temperature in the VNIIPO formula should be expressed in Kelvin, so as not to lead to false results when the temperature tends to zero on the Celsius scale.

D. A. Frank-Kamenetsky overcame these shortcomings by analytically solving the stationary problem of thermal self-ignition [11]:

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[23] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[24] Idem.

[25] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[26] Belozerov V. V. On the expediency of revising the basic "fire" standards.

$$\frac{E}{RT_O^2}\cdot\frac{Q\ell^2}{\lambda}\cdot k\cdot\exp\left(-\frac{E}{RT_O}\right)\geq\delta_{КР}\tag{3}$$

where, $\delta_{КР}$ — th dimensionless Frank-Kamenetsky criterion; λ — the material thermal conductivity coefficient, $W\cdot m^{1}\cdot K^{-1}$; *r* — the determining size of the material (combustible medium), m. The other variable designations were given above.

The criterion was calculated by D. A. Frank-Kamenetsky under the condition of unlimited heat transfer for three basic geometric shapes: a cylinder (2.00), a ball (3.32) and a plane (0.88). Later, with the guidance of A. G. Merzhanov, such dependence was found for natural heat exchange [12]:

$$\delta_*=\frac{8a_*^2}{\left(a_*^2+1\right)^2}\cdot\exp\left\{\frac{-4a_*^2}{\left(a_*^2+1\right)Bi}\right\}\quad a_*=\sqrt{\sqrt{\frac{4}{Bi^2}+1}-\frac{2}{Bi}}\tag{4}$$

where $Bi=\alpha\cdot\ell/\lambda$ — the number of Bio (including radiation: $Bi_p=\sigma\cdot T^3\cdot\ell/\lambda$).

However, due to the approximation of the Arrhenius exponent by the Frank-Kamenetsky series, his method has the following disadvantages [27], [28] [10]:

— mathematical complexity and practical inconvenience of using dimensionless parameters;

— incorrect assumption about the nonlinearity of the heat sink from the sample with internal heat removal, and as a result — inconsistency with the critical condition of thermal self-ignition according to the Semenov diagram.

These shortcomings were eliminated by the method of Y. S. Kiselev. He introduced into the Semenov equation a criterion named after him — the ratio of the derivatives of the heat release rates, as well as the pre-exponent of the volumetric reaction rate and the criterion of uneven heating [10]:

$$\frac{E}{RT^2}\cdot\frac{QZ}{\rho\cdot c_P}\cdot exp\left(-\frac{E}{RT}\right)\geq\frac{\psi\cdot Se\cdot\alpha\cdot F}{\rho\cdot c_P\cdot V},\tag{5}$$

where *E* — activation energy, $J\cdot mole^{-1}$; *R* — gas constant, 8,3 $J\cdot mole^{-1}\,K^{-1}$; *Q* — thermal effect of the reaction, $J\cdot mole^{-1}$; c_P — specific heat capacity $J\cdot kg^{-1}\cdot K^{-1}$; ρ — density of the material, $kg\cdot m^{-3}$; α — heat transfer coefficient, $W\cdot m^{-2}\cdot K^{-1}$; *F* — surface area, m^2; *V* — volume of the material, m^3; $Q\cdot Z/\rho\cdot C_P$ — pre–exponent of the volumetric reaction rate, $mole\cdot m^{-3}\cdot c^{-1}$; *T* — self-ignition temperature of the substance (combustible mixture) and the environment, K; $T_0=T-RT^2/E$ (Todes ratio) — ambient temperature, K; $\psi=\frac{n\cdot\lambda}{\alpha\cdot\ell+n\cdot\lambda}$ — the Kiselev criterion, where the relative gradient *n* for a plane, an infinite cylinder, a sphere, a cube and a finite cylinder is 2.38; 2.71; 3.01; 2.29 и 2.50 respectively.

The approach developed by Ya. S. Kiselev, which is based on the analysis of heat flows, also has a number of disadvantages. In particular, the relative gradient introduced in it does not have a calculation function yet. At the same time, its advantage is obvious, since the formulas of Semenov, Frank-Kamenetsky and Taubkin (VNIIPO) are partial solutions to his equation (5).

The second approach describing ignition (in particular, ignition by a flat wall) was developed by academician Ya. B. Zeldovich. He determined the critical density of the heat flux and derived the following equation for the dimensional value of the heat flux [13]:

$$q=\sqrt{2\lambda\frac{RT_S^2}{E}\cdot Q\cdot k\cdot exp\left(-\frac{E}{RT_S}\right)}.\tag{6}$$

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[27] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[28] Belozerov V. V. On the expediency of revising the basic "fire" standards.

Here q — critical heat flux density, W/m^2; T_S — wall temperature, °K; λ — thermal conductivity coefficient of the gas phase. The rest designations of the variables are given above.

Another criterion for ignition of the condensed substances heated by a thermal pulse was proposed by corresponding member of the USSR Academy of Sciences A. A. Kovalsky and academician A. G. Merzhanov [14, 15]:

$$\frac{1}{\alpha} ln\, F(\gamma)\cdot q\cdot K_0\, exp\left(-\frac{E}{RT_m}\right)=\frac{\lambda\cdot\alpha\cdot\Delta T_m}{F(\gamma)}\text{ here } F(\gamma)=\frac{1+RT_m/E}{1-RT_m\cdot T_0/\Delta T_m} \tag{7}$$

Here T_m — ignition temperature, T_0 — sample temperature. The rest designations of the variables are given above.

I. S. Lyubchenko and corresponding member of the Academy of Sciences of the Republic of Tatarstan G. N. Marchenko proposed an asymptotic ignition criterion for reacting condensed substances:

$$q=1{,}39\sqrt{\sqrt{\left(\frac{E(T_S-T_O)}{RT^2}\right)}\cdot\frac{\lambda\cdot\rho\cdot Q\cdot K\cdot RT^2}{E}\exp\left(\frac{E_a}{RT}\right)} \tag{8}$$

Here T_S — wall temperature, T_o — sample temperature. The rest designations of the variables are given above.

Taking into account the stationary heat removal from the reaction zone, the critical equation of the heat flux density (including for a non-degenerate ignition mode with asymmetric heating) clarifies the Zeldovich formula [13, 17]:

$$q^2=2\lambda\cdot\rho\cdot\frac{RT_S^2}{E}\cdot Q\cdot K\cdot exp\left(-\frac{E}{RT_S}\right) \tag{9}$$

All these approaches describe well enough the particular cases of fires. However, they, firstly, do not allow predicting the occurrence of fires in real operating conditions of industrial and residential facilities. Secondly, finding the activation energies included in the above equations is a difficult experimental task for any material. The problem is caused by the fact that instrument methods and means do not allow you to create isothermal conditions and to fix the parameters of the stages of melting, smoldering and ignition of substances and materials with the necessary accuracy and reliability[29, 30].

The third approach, integrating all the previous ones, was developed by Rostov scientists together with the staff of the Academy of State Fire Service of the Ministry of Emergency Situations of Russia[31,32,33,34] [4, 7]. It made it possible to overcome these methodological and instrumental difficulties, and most importantly — to link the parameters of the ignition and combustion processes[35] with the probability of a fire[36].

The proposed method of baroelectrothermoacustometry (BETA) and BETA-analyzer, that implements it, allow you to define multivariable vector-function of the life cycle (VGLC) of a sample of any material —F [P, T, m_i, ℓ_i, ρ_i, λ_i, a_i, Cp_i, Cv_i, β_i, γ_i, ζ_i, h_i, χ_i, ψ_i, H_i, Fo_i, B_i, E_i, K_i, G_i, v_i, $\rho_i g\cdot\ell_i/E_i$, σ_i,$|Z_i|$, $C_i(R_i)$, $tg\sigma_i$, ε_i, μ_i, $\mu_i\cdot\ell_i 2/\sigma_i t$, $L_i/R_i t$,$\varepsilon_i\cdot\sigma_i/t$,$C_i/\sigma_i t$,$Na_i$,$U_i$,$G_i$,$\eta_i$). The changes in the VGLC are made up into a function of entropy production without data loss on reversible and irreversible processes up to destruction or ignition and combustion of the sample[37, 38, 39] [18] In contrast to the previous solutions, it is proposed to reduce the Semyonov and Zeldovich inequalities with the Franz-Kamenetsky and Lyubchenko—Marchenko equations into a system of equations (10) in order to use a BETA analyzer

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[29] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[30] Molchadskiy O. I., Smirnov N. V., Duderov N. G. Op. cit.

[31] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[32] Belozerov V. V., Belozerov V. V., Bosyy S. I. et al. Method of synchronous-coupled thermal analysis of substances and materials and installation for its implementation. Patent 2343467 Russian Federation, IPC G01N 27/00/No. 2006125486/28, 2009, 26 p.

[33] Belozerov V. V. On the expediency of revising the basic «fire» standards.

[34] Belozerov V. V., Buylo S. I., Prus Yu. V. Combined thermogravimetric and acoustic emission method for determining the stages of thermal degradation of substances and materials and a device for its implementation. Patent 2324923 Russian Federation, RU 2006 126 287 A/No. 2006126287/28; 2008, 1 p.

[35] GOST 12.1.044 Fire and explosion hazard of substances and materials. Nomenclature of indices and methods of their determination.

[36] GOST 12.1.004 Fire safety. General requirements. Moscow: Publishing House of Standards.

[37] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[38] Method of synchronous-coupled thermal analysis of substances and materials and installation for its implementation.

[39] Combined thermogravimetric and acoustic emission method for determining the stages of thermal degradation of substances and materials and a device for its implementation.

to find a solution at the ignition point of the sample recorded by acoustic emission signals, taking into account the design (Fig. 4) of the thermoelectrodylatometer crucible (TED) and the assumptions that are given after explication[40, 41]:

$$\begin{cases} Se = \dfrac{Q \cdot V}{F \cdot \alpha} \cdot \dfrac{E_a K_{Se}}{RT_{\text{ПО}}^2} \cdot \exp\left(-\dfrac{E_a}{RT_{\text{ПО}}}\right) \\ q = \sqrt{\dfrac{2\lambda_B RT_{\text{ПО}}^2 \cdot Q \cdot K_{Ze}}{E_a} \cdot \exp\left(-\dfrac{E_a}{RT_{\text{ПО}}}\right)} \\ F_{\kappa} = \dfrac{Q \cdot r^2}{\lambda_O} \cdot \dfrac{E_a}{RT_O^2} \cdot K_{Fk} \cdot \exp\left(-\dfrac{E_a}{RT_O}\right) \\ q^2 = \dfrac{2\lambda_O \rho \cdot Q \cdot K_{Lu} \cdot RT_{\text{ПО}}^2}{E_a} \cdot \exp\left(-\dfrac{E_a}{RT_{\text{ПО}}}\right) \end{cases} \tag{10}$$

Here q — critical heat flux density; λ_B — thermal conductivity coefficient of the gas phase (air); λ_O — thermal conductivity coefficient of the sample; ρ — sample density; R — gas constant; E_a — activation energy of the processes in the sample; Q — thermal effect of the reaction; Ki — pre-exponents; Se — the Semenov criterion ($Se = 0.368$); V — current volume of the sample; F — current surface area of the sample; α — current heat transfer coefficient of the sample; $T_{\text{ПО}}$ — surface temperature of the sample; $F\kappa$ — the Frank—Kamenetsky criterion ($F\kappa = 2.00$); r — characteristic size of the sample; $To = T_{\text{ПО}} - (T_{\text{ПО}} - T_H)/2$ — average temperature of the sample.

Here are the assumptions mentioned above.

— The test samples are made in the form of a cylinder (viscous and liquid are poured into a thin molybdenum "glass") and placed in a thermoelectrodylatometer (TED). It is equipped with a movable "float" and two fixed temperature sensors (Fig. 4). The temperature of the bottom Tb and the temperature of the cover Tc are equal to the temperature of the furnace. The surface temperature of the sample is Ts. The average volume value of the sample temperature: $TV = (T_b - Ts)/2$.

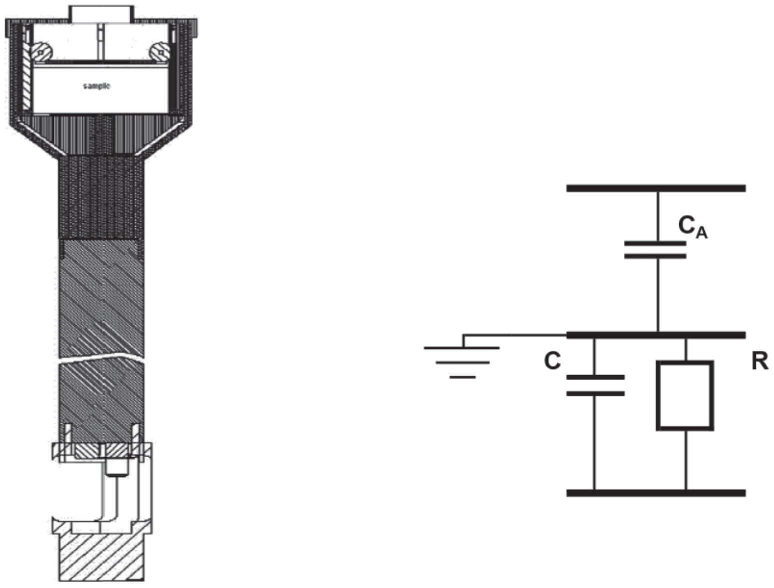

Fig. 4. Thermoelectrodylatometer for solid, liquid and viscous materials and its equivalent circuit

— The stages of thermal destruction and the moment of ignition are recorded using two AE sensors installed at the outer ends of molybdenum thermoacoustic waveguide rods. Two of their half-cones are inserted into the bottom of the TED and are in contact with the test sample.

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[40] Belozerov V. V. Methods, models and automation tools for technosphere safety management.
[41] Belozerov V. V. On the expediency of revising the basic "fire" standards.

— TED (fig. 4) is made of zirconium ceramics. Its thermal conductivity coefficient is about 1.0 W/(m•K). Molybdenum plates (bottom, cover and movable "float") have thermal conductivity coefficient of about 130 W/(m•K) and allow you to create a unidirectional adjustable heat flow into the sample with a determined density q(W/m^2) and lateral heat dispersion of less than 1 %.

These assumptions, according to the author, are correct if we take into account that the Semenov equation uses the heat transfer coefficient from the sample surface [9], the Frank-Kamenetsky and Lyubchenko—Marchenko equations use the thermal conductivity coefficient of the sample [11, 12], and the Zeldovich equation uses the thermal conductivity coefficient of the gas phase from the "wall" to the sample (in this measurement scheme — to the float). That is, the temperature of the ignition wall is the temperature of the float on the surface of the sample [42] [13].

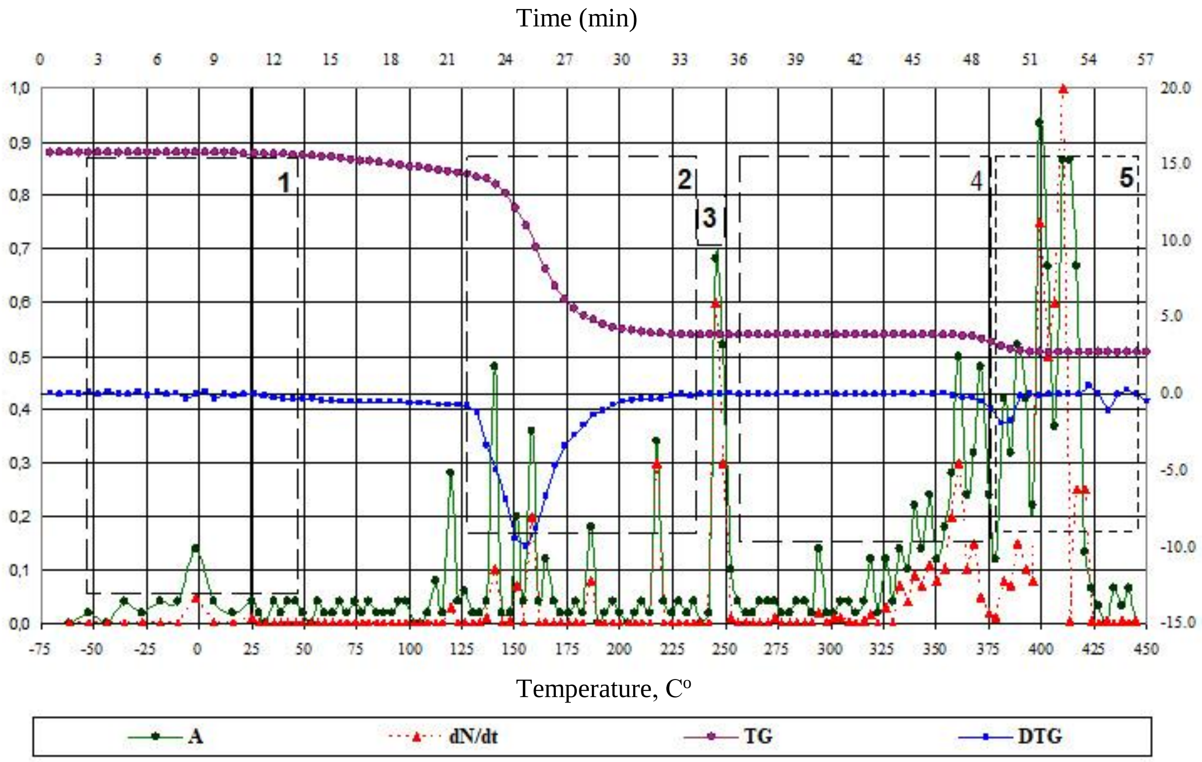

Fig. 5. Thermograviacustometry of the polymer: 1 —zone of thermal destruction of the sample during operation (from –50 °C to +50 °C); 2 —pyrolysis zone of the sample; 3 — ignition point of the sample; 4 —combustion of the sample; 5 — zone of coke residue formation. The normalized amplitude and the intensity of acoustic emission are shown on the left scale, and the change in the mass of the sample in grams is shown on the right scale

During thermal cycling (heating — cooling) of a sample, it is possible to register and calculate the thermokinetic parameters (E_{Di} and QK_{Di}) of the stages of its thermal destruction: crystallization, occurrence of flow channels, melting or evaporation, pyrolysis, ignition, combustion and coke residue formation (Fig. 5). All this is reliably recorded by AE signals. According to these stages, it is possible to construct vector functions of the life cycle (VFLC) of the sample, including the aging processes during operation[43, 44, 45, 46] [18].

High accuracy of the VFLC parameters is ensured by the dynamic metrology of the measuring channels of the beta analyzer using thermodynamic acoustic emission standards built into TED. These standards, which are "droplets" of mercury and water, are soldered into the thermoacoustic waveguide rods, forming the "TED bottom". Due to the

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[42] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[43] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[44] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[45] Method of synchronous-coupled thermal analysis of substances and materials and installation for its implementation.

[46] Combined thermogravimetric and acoustic emission method for determining the stages of thermal degradation of substances and materials and a device for its implementation.

anhysteretical characteristics of phase transitions of the first kind, they allow calibration of measuring channels during tests. The method of such standardization is protected by a patent of the Russian Federation[47].

We will take into account the initial calibration of the sample in TED before testing under normal conditions: the exact determination of mass — *m*, linear size — *ℓ*, density calculation — ρ, volume — *V*, sample radius — *r* and coefficient $\psi = r/\ell$). In this case, to solve system (10), the following measured TED parameters are substituted into its equations and the following formulas are used:

— the current radius of the sample (characteristic dimension) *r* → (m) $r = \psi\cdot\ell(T)$;

— the current thermal conductivity coefficient of the sample → (W/m·°K) $\lambda_O(T)$;

— the current heat transfer coefficient of the sample → (W/m^2·°K) $\alpha = Bi\cdot\lambda_O(T)/\ell(T)$, where the number of Bio is given by e $Bi = \sigma T^3\ell(T)/\lambda_O(T)$;

— the current volume of the sample → (m^3) $V(T) = \pi\cdot\psi^2\cdot\ell^3(T)$;

— the current surface area of the sample (cylinder) → (m^2) $F(T) = 2\pi\cdot\psi^2\cdot\ell^2(T) + 2\pi\cdot\psi\cdot\ell^2(T) = 2\pi\cdot\psi\cdot\ell^2(T)\cdot(\psi+1)$.

In the last case, the initial calibration of the sample in TED before testing under normal conditions is taken into account (accurate determination of mass *m*, linear size *ℓ*, as well as density calculation ρ, volume *V*, sample radius *r* and coefficient $\psi = r/\ell$).

System (10) is solved by substitution in several stages. This is how it differs from previous methods [48, 49] taking into account the results of the analysis of the dimension of variables in the equations.

First step. By dividing the second equation by the third (*Se*/*Fк*) with substitution of the values of all variables measured at the ignition point, the ignition activation energy E_a is determined:

$$\frac{Se}{F_K}=\frac{\lambda_O R T_O^2\cdot Q\cdot V\cdot E_a\cdot K\exp\left(-\dfrac{E_a}{RT_{ПО}}\right)}{r^2 Q\cdot E_a K\exp\left(-\dfrac{E_a}{RT_O}\right)RT_{\text{ПО}}^2\cdot F\cdot\alpha\cdot}=\frac{T_O^2\exp\left(\dfrac{E_a}{RT_O}\right)}{2\psi\ (\psi+1)\cdot T_{\text{ПО}}^2\cdot\text{Bi}\cdot\exp\left(\dfrac{E_a}{RT_{ПО}}\right)}.=\frac{T_O^2}{2\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\cdot\text{Bi}}\exp\left(\frac{E_a}{RT_O}-\frac{E_a}{RT_{ПО}}\right)\cdot$$

Let us substitute the criteria of Semenov and Frank-Kamenetsky (for the cylinder-sample) and find the logarithm:

$$E_a\left(\frac{T_{ПD}-T_O}{RT_O T_{ПD}}\right)=\ln\frac{F_K\cdot T_O^2}{2Se\cdot\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\text{Bi}}\to E_a=\frac{RT_O T_{ПD}}{T_{ПD}-T_O}\cdot\ln\frac{e\cdot T_O^2}{\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\text{Bi}}\,. \tag{11}$$

Second step. Let us substitute (11) into the equations of system (10) and determine thermokinetic complexes *QKi*:

$$Se=\frac{Q\cdot\pi\cdot\psi^2\cdot\ell^3\cdot\dfrac{RT_O T_{ПD}}{T_{ПD}-T_O}\cdot\ln\dfrac{e\cdot T_O^2}{\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\text{Bi}}\cdot K_{Se}}{2\pi\cdot\psi\cdot\ell^2(\psi+1)\cdot\dfrac{Bi\cdot\lambda_O}{\ell}\cdot RT_{ПО}^2}\cdot\exp\left(-\frac{\dfrac{RT_O T_{ПD}}{T_{ПD}-T_O}\cdot\ln\dfrac{e\cdot T_O^2}{\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\text{Bi}}}{RT_{ПD}}\right)\to$$

$$QK_{Se}=\frac{2(\psi+1)\cdot Bi\cdot\lambda_O\cdot T_{ПО}(T_{ПD}-T_O)}{e\cdot\psi\cdot\ell^2\cdot T_O\cdot\ln\dfrac{e\cdot T_O^2}{\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\text{Bi}}}\cdot\exp\left(\frac{T_O}{T_{ПD}-T_O}\cdot\ln\frac{e\cdot T_O^2}{\psi(\psi+1)\cdot T_{\text{ПО}}^2\cdot\text{Bi}}\right) \tag{12}$$

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[47] Belozerov V. V., Bosyy S. I., Buylo S. I. The method of thermodynamic acoustic emission standardizing and the system implementing it. Patent 2399910 Russian Federation,: G01N 25/02, G01N 29/14/. No. 2399910, 2010.

[48] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[49] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

$$q^2 = \frac{2\lambda_B RT_{ПО}^2 \cdot Q \cdot K_{Ze}}{\frac{RT_O T_{ПО}}{T_{ПО} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot \mathrm{Bi}}} \cdot \exp\left(- \frac{\frac{RT_O T_{ПО}}{T_{ПО} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot \mathrm{Bi}}}{RT_{ПО}} \right) \rightarrow$$

$$QK_{Ze} = \frac{q^2 T_O \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot Bi}}{2\lambda_B T_{ПО}(T_{ПО} - T_O)} \exp\left(\frac{T_O}{(T_{ПО} - T_O)} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot Bi} \right) \tag{13}$$

$$F_к = \frac{Q \cdot K_{Fk} \cdot \psi^2 \ell^2 \frac{RT_O T_{ПО}}{T_{ПО} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot \mathrm{Bi}}}{\lambda_O RT_O^2} \cdot \exp\left(- \frac{\frac{RT_O T_{ПО}}{T_{ПО} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot \mathrm{Bi}}}{RT_O} \right) \rightarrow$$

$$QK_{Fk} = \frac{2\lambda_O T_O (T_{ПО} - T_O)}{\psi^2 \ell^2 T_{ПО} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot \mathrm{Bi}}} \exp\left(\frac{T_{ПО}}{T_{ПО} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot \mathrm{Bi}} \right) \tag{14}$$

$$q^2 = \frac{2\lambda_O \rho \cdot RT_{ПО}^2 \cdot Q \cdot K_{Le}}{\frac{RT_O T_{ПО}}{T_{ПО} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot \mathrm{Bi}}} \cdot \exp\left(- \frac{\frac{RT_O T_{ПО}}{T_{ПО} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot \mathrm{Bi}}}{RT_{ПО}} \right) \rightarrow$$

$$QK_{Le} = \frac{q^2 T_O \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot Bi}}{2\lambda_O \rho \cdot T_{ПО}(T_{ПО} - T_O)} \exp\left(\frac{T_O}{(T_{ПО} - T_O)} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1)\cdot T_{ПО}^2 \cdot Bi} \right) \tag{15}$$

Formulas (11–15) allow recording and calculating thermokinetic parameters (E_{Di} и QK_Di) of all stages of thermal degradation of samples.

Researches [50, 51, 52, 53, 54] [18] show that prior to mass loss of the sample as a result of the processes of thermal destruction (i.e., before the registration of m_0 changes) the thermal energy received by the sample goes to:

— the change its structure and temperature, i.e. heating and phase transitions (flow thresholds, melting, etc.), which is registered by the acoustic emission signals (Fig. 5);

— the interaction (heat exchange and radiation) with the environment.

Therefore, it can be argued that the activation energy at the ignition point E_a is the bond energy E_b, i.e. the following equalities can be used [19]:

$$E_b = ST = \Delta mc^2, \tag{16}$$

$$E = E_o + E_b + A = m_o c^2 + \Delta mc^2 + A. \tag{17}$$

Here E_b — energy spent on the formation of new internal connections, including changes in the mass and volume of the sample; S — energy spent on the formation of new internal connections, including changes in the mass and volume of the sample; T — absolute temperature characterizing in this case the speed of processes in the object;

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[50] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.

[51] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

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[53] Combined thermogravimetric and acoustic emission method for determining the stages of thermal degradation of substances and materials and a device for its implementation.

[54] The method of thermodynamic acoustic emission standardizing and the system implementing it.

Δm — change in the mass of the object; c — the speed of light; E — the total energy of the object under consideration; E_o — internal energy; A — energy spent on superfacial work (free energy); m_o — mass of the object.

In this case, activation energy equation (11) can be written as follows [55]:

$$E_a = ST_O = \frac{RT_O T_{\text{ПD}}}{T_{\text{ПD}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}} \tag{18}$$

From here we get a formula for calculating the entropy of dissipation (activation):

$$S = \frac{RT_{\text{ПD}}}{T_{\text{ПD}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}} \tag{19}$$

Let us substitute expressions (18 and 19) in (10) and write a new system (20). It will make it possible to obtain thermokinetic complexes (QK_{Di}) of samples (21)–(24) at all stages of the life cycle, for subsequent calculation through the difference between the stages — entropy production functions (ΔSi) which characterize the degradation of properties:

$$\begin{cases} Se = \dfrac{Q \cdot V \cdot S \cdot K_{Se}}{F \cdot \alpha \cdot RT_{\text{ПО}}} \cdot exp\left(-\dfrac{S}{R}\right); \\ q = \sqrt{\dfrac{2\lambda_B RT_{\text{ПО}} \cdot Q \cdot K_{Ze}}{S} \cdot exp\left(-\dfrac{S}{R}\right)}; \\ F_{\kappa} = \dfrac{Q \cdot \psi^2 \ell^2 S \cdot K_{Fk}}{\lambda_O RT_O} \cdot exp\left(-\dfrac{S}{R}\right); \\ q^2 = \dfrac{2\lambda_O \rho \cdot Q \cdot K_{Lu} \cdot RT_{\text{ПО}}}{S} \cdot exp\left(-\dfrac{S}{R}\right). \end{cases} \tag{20}$$

$$QK_{Se} = \frac{2(\psi+1)Bi \cdot \lambda_O \cdot T_{\text{ПО}}(T_{\text{ПD}} - T_O)}{e \cdot \psi \cdot \ell^2 \cdot \ln \dfrac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}} \cdot \exp\left(\frac{T_O}{T_{\text{ПD}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}\right) \tag{21}$$

$$QK_{Ze} = \frac{q^2 T_O \cdot \ln \dfrac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot Bi}}{2\lambda_B T_{\text{ПО}}(T_{\text{ПО}} - T_O)} \exp\left(\frac{T_O}{T_{\text{ПD}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}\right) \tag{22}$$

$$QK_{Fk} = \frac{2\lambda_O T_O(T_{\text{ПО}} - T_O)}{\psi^2 \ell^2 T_{\text{ПD}} \cdot \ln \dfrac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}} \exp\left(\frac{T_{\text{ПD}}}{T_{\text{ПD}} - T_O} \cdot \ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot \mathrm{Bi}}\right) \tag{23}$$

$$QK_{Le} = \frac{q^2 \cdot ln \dfrac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot Bi}}{2\lambda_O \rho \cdot T_{\text{ПО}}(T_{\text{ПО}} - T_O)} exp\left(\frac{T_O}{(T_{\text{ПО}} - T_O)} \cdot ln \frac{e \cdot T_O^2}{\psi(\psi+1) \cdot T_{\text{ПО}}^2 \cdot Bi}\right) \tag{24}$$

This demonstrates the possibility of implementing an analytical, quantitative approach to the fire hazard of materials. There is an obvious need to replace the methods and means of their determination. Instead of GOST 12.1.044, a new edition should be introduced, which uses methods and means of baroelectrothermoacoustic beta analysis, which are developed in Russia [56, 57, 58, 59, 60] [18].

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[55] Belozerov V. V. Methods, models and automation tools for technosphere safety management.
[56] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.
[57] Belozerov V. V. Methods, models and automation tools for technosphere safety management.
[58] Method of synchronous-coupled thermal analysis of substances and materials and installation for its implementation.

In this case, from the point of view of further interaction of these basic standards, of course, it is necessary to correct GOST 12.1.004. It is necessary to eliminate errors in the dimension of events and in the method of "introducing malfunctions in electrical appliances". Let us take a closer look at the weaknesses of this document [61, 62, 63].

First, the probability of any event is a dimensionless quantity. However, GOST 12.1.004 (as well as the "Technical Regulations on fire safety requirements") fixes the permissible level of probability of fire in equipment or object (in the "Technical Regulations" we are talking about fire risk) 10^{-6} per year. From the point of view of reliability and probability theories, this is the intensity of the event λ with a generally accepted dimension of 1/hour. In other words, $1.14 \cdot 10 - 10$ hour^{-1}, because one millionth has to be divided into 8760 hours, of which the year consists [64].

Secondly, for fire hazard tests of radio-electronic and electrical equipment and devices, the methodology for introducing malfunctions fixed in these documents is used. It must be excluded. The fact is that this erroneous approach requires the application of a complex section of reliability theory — the theory of dependent failures. Artificial "shutdown", i.e., the closure or breakage of any RE of the product activates the emergency mode not in it, but in schematically connected other electrical and radio elements. This causes the incorrectness of further calculation of the probability of fire, because the conditions of applicability of probability distribution formulas requiring independence of events are violated[65, 66, 67].

The first error can be eliminated by introducing the concept of "fire-safe resource" (material, product, etc.) and the requirements of its commensurability with the technical resource, i.e. with the service life of the material, equipment, premises and object. The correct wording would be: "The probability of a fire in the equipment or object should not exceed 10^{-6} during its service life." We will show how in this case (for example, taking into account the exponential distribution generally accepted in GOST R 27.403) the permissible intensity λ_A is determined when creating (designing and manufacturing) a product (object). Knowing the time of consumption of the "fire-safe resource" during operation (t_{FR}), we log the distribution function:

$$10^{-6} = 1 - \exp(-\lambda_A t_{FR}) \rightarrow \quad \lambda_A = \left(\frac{\ln(1) - \ln(1 - 10^{-6})}{t_{FR}} \right) \tag{25}$$

It is appropriate to recall that Federal Law 123-FZ "Technical Regulations on fire safety requirements"[68] introduced the concept of "fire risk". According to the author, this, firstly, is not justified by anything. Secondly, it confuses and contradicts the concept of the risk function — $h(x)$. In the probability theory, it is defined as the ratio of the probability density function — $f(x)$ to the survival function — $S(x)$ at point x. With an exponential distribution, its value is equal to the intensity of the event — λ_A, i.e. in this case, the intensity of the fire [69, 70, 71]:

$$h(t_П) = \frac{f(t)}{S(t)} = \frac{\lambda_П \exp(-\lambda_П \cdot t_{ПБР})}{\exp(-\lambda_П \cdot t_{ПБР})} = \lambda_П . \tag{26}$$

It is advisable to eliminate the second error using a probabilistic-physical model obtained in the form of lognormal distribution functions. What is meant here is the additional heat of each element in a fire hazard failure:

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[59] Combined thermogravimetric and acoustic emission method for determining the stages of thermal degradation of substances and materials and a device for its implementation.
[60] The method of thermodynamic acoustic emission standardizing and the system implementing it.
[61] Belozerov V. V. Automated testing system for materials of electrotechnical and radioelectronic industry with control of their fire hazard.
[62] Belozerov V. V. Methods, models and automation tools for technosphere safety management.
[63] Belozerov V. V. On the expediency of revising the basic "fire" standards.
[64] GOST R 27.403-2009 Dependability in technics. Compliance test plans for reliability.
[65] Belozerov V. V. Methods, models and automation tools for technosphere safety management.
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[68] Technical regulations on fire safety requirements.
[69] Belozerov V. V. Methods, models and automation tools for technosphere safety management.
[70] Belozerov V. V. On the expediency of revising the basic "fire" standards.
[71] GOST R 27.403-2009 Dependability in technics. Compliance test plans for reliability.

$$F_e\,(Q) = 1 - v_e\,[1 - G_e(z)], \tag{27}$$

where $F_e(Q)$ — the probability of additional heat release; v_e — share of fire hazard failures (short circuit, break); $G_e(Z)$ — conditional distribution function (in the event of failure of the fire element) of a random variable $Z = \lg Q$, where $Q = k{\cdot}U{\cdot}I{\cdot}t$ — Joule heat of the fire element failure.

In this case, during the transition of the destruction and pyrolysis processes into a self-accelerating phase according to the criteria of Semenov and Frank-Kamenetsky, the heat release of a fire-hazardous failure leads to heating and self-ignition of the material of the failed RE. Another scenario is also possible. The heat release of a fire-hazardous failure "ignites" the neighboring RE according to the criterion of Zeldovich and Lyubchenko — Marchenko. This happens if the heat flux density is critical for the "neighbor" and its surface temperature reaches the ignition temperature.

RE failure rates must be determined by the modified Arrhenius — Eyring equation [72, 73]:

$$\lambda = A\left(P,V,N,F\right)\frac{\mathrm{k}T\,\cdot}{h}\cdot\exp\cdot\left(-\frac{E_a}{\mathrm{k}T}\right)\cdot\exp\cdot\left[\,f\left(H\right)\right], \tag{28}$$

where λ — current RE failure rate; $A = k_i{\cdot}\lambda_n$ — product of factors that are dependent on pressure, humidity, vibration, etc., as well as the nominal failure rate RE (λ_n); k — the Boltzmann constant; T — RE temperature; h — the Planck's constant; E_a — the effective activation energy of the RE failure; $f\,(H)$ — function non-thermal (energy) RE load.

The Arrhenius — Eyring equation (28) should be solved for each RE in the product by thermosounding the internal volume of the product $[T(t)]$ and the ambient air $[T_A(t)]$ while simultaneously measuring the energy consumed by the product $[E(t)]$ by solving the Navier-Stokes heat balance equations (direct and inverse problems of thermal location). As a result, the temperatures (T) and the current values of the energy load functions of each RE $[f_i(H)]$, are determined, and the values of the activation energy functions of each RE are selected on the "smooth surfaces" of the functions $[E_a(H,T)]$, obtained by solving equation (28) from three reference values of failure rates — storage, nominal and maximum permissible[74].

In this case, it is possible to determine the intensity of RE fire-hazardous failures ($\lambda_{fh} = \lambda_{H,T}{\cdot}v_e$) and the intensity of their ignition ($\lambda_{ign} = \lambda_{fh}{\cdot}F_e$), since the critical thermal parameters for each RE are known. Further, by integrating, it is possible to calculate the probability of RE ignition (F_{ign}), which will eliminate the methodological and logical incompleteness of the fire hazard assessment of any product or object. After that, by adding the heat capacity of the combustion of the ignited RE to the critical thermal parameters of the RE surrounding it, it is possible to calculate the spread of fire according to the same critical parameters, which will allow determining the probability of a fire in the product. [75].

Similarly, using expressions for entropy and energy (18), (19), the Arrhenius-Eyring equation can be used in entropic form:

$$\lambda = A\left(P,V,N,F\right)\frac{\mathrm{k}T\,\cdot}{h}\cdot\exp\cdot\left(-\frac{S_O}{\mathrm{k}}\right)\cdot\exp\cdot\left[\,f\left(H\right)\right], \tag{29}$$

where S_O — the entropy of the failure of the electric radio element. For the rest of the notation (28).

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[72] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

[73] Belozerov V. V. On the expediency of revising the basic «fire» standards.

[74] Belozerov V. V. On the expediency of revising the basic «fire» standards.

[75] Belozerov V. V. Methods, models and automation tools for technosphere safety management.

Conclusions. The analysis of the main "fire" standards and norms revealed their inconsistency with the current state of science and technology. It is noted that fundamental science pays insufficient attention to "fire problems", which are applied problems of the theory of combustion and explosion, physical chemistry, thermophysics and thermodynamics.

The paper presents the results of the system synthesis of the main approaches in the theory of combustion (ignition) and methods and means of thermal and acoustic emission analysis. Thus, a probabilistic-physical method for determining the flammability and fire hazard of substances, materials, electrical appliances and household items is implemented. This will ensure the required level of protection of the population and objects of the technosphere from fires.

The entropy approach to diagnostics of safety and reliability of technogenic and natural systems where there are people is offered. In this case, the minimum acceptable security level is 0.999999.

The results of the revision of shortcomings and errors in fire safety standards and norms that arose due to the "industry" approach to their development and should be corrected are presented.

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