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IGNITION DETECTION METHOD BASED ON REAL-TIME MEASUREMENTS OF A HAZARDOUS PARAMETER IN THE ENVIRONMENT

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The object of this study is a selective average of the dangerous parameters of the gas environment during the ignition of materials. Theoretical substantiation of the fire detection method based on testing the null hypothesis regarding the current difference of the specified selective averages of an arbitrary dangerous parameter of the gas environment has been performed. In this case, the significance of the current difference with respect to selective averages allows detection of ignition in real-time observation of an arbitrary dangerous parameter of the gas environment. The method makes it possible to set the level of significance for the current difference and at the same time provide for the maximum power of fire detection. Laboratory experiments were conducted to verify the proposed method for detecting ignition based on the current difference of the selective averages of the measured dangerous parameters of the gas environment corresponding to the training and control general population. The results of verification showed that at a given level of significance, the method allows detecting current fires of materials based on significant differences in sample means. It was established that the current difference in the concentration of carbon monoxide during ignition and after ignition of alcohol, paper, wood shavings, and textiles is –0.459 and 8.296, –0.152 and 4.299, –0.027 and 6.9, –0.262 and 2.3, respectively. Current smoke density differences are 0.043 and 0.391, 0.012 and 0.923, –0.139 and –0.235, 0.034 and 0.129 and temperatures are –0.01 and 10.635, 0.53 135 and 2.726, respectively. This means that the current difference is significant and is due not to a random nature but to the appearance of a persistent effect from the ignition of the material. In practice, research results can be used to detect fires in real time in order to prevent them from growing into an uncontrolled fire

Keywords: detection of fires, selective average, dangerous parameters, gas environment, ignition of material

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1. Introduction

Development of humankind has provoked the predominance of man-made threats over natural ones. Critical infrastructure facilities should be considered the main sources of threats under war conditions. These include strategically important objects for the sustainable functioning of the population and economy of the country. At the same time, energy generation facilities are the most dangerous since they pose not only significant anthropogenic, radiation, and environmental hazards [1]. Dangerous events at oil and gas industry facilities are characterized by the highest development speed and require the immediate concentration of significant resources to suppress them. It should be noted that the greatest danger in terms of the intensity of such events is fires (Fs). Fs pose a serious threat to human life and lead to the destruction or damage of objects. The largest part of Fs falls on residential, public, and industrial facilities. Maximum material damage is caused to industrial and residential facilities. Moreover, the maximum number of deaths is typical for indoor fires (80 %) [2]. Reducing the danger of fires in premises can be implemented on the basis of early detection of ignition (I), which are a harbinger of any fire. Therefore, it is relevant to improve the quality of detection of ignition (DI) in real time.

2. Literature review and problem statement

Analysis [3] showed that traditional F detection systems use sensitive sensors (S) for measuring various hazardous F factors. Such S limit the capabilities of early detection of Fs (EDF) by traditional F detection systems. This is explained by the fact that the F detection stage should be one at which the hazardous parameter (factor) (HUY) of the gaseous medium (GasMas) reaches the corresponding C and the value of this parameter exceeds the established threshold. During this time, Fs may have a stage different from the stage Z of the material. The impossibility of EDF based on C measurement of GasMas HUY is due to the lack of taking into account the current features of the real dynamics of GasMas HUY at stage I of materials. In this regard, in [4], the features of the real dynamics of HUYa of a heterogeneous system for Z of different types of materials are studied. It is shown that the dynamics of the GasMas HUY is complex, nonlinear, and individual in nature. It has been established that the features of the dynamics of GasMas HUYa are reflected in characteristic changes in the amplitudes of the bispectrum. However, methods for early detection of Z (DF) based on changes in the amplitudes of the bispectrum of HUYa dynamics are not considered. In [5], the results of an experimental study of the combustion characteristics of coniferous and hardwood wood at three fixed levels of 30, 40 and 50 $kW \cdot m^{-2}$ heat source are reported. The complex and individual nature of combustion of these types of wood has been experimentally confirmed. The presence of two characteristic peaks in the rate of heat release and smoke was established throughout the entire range of thermal exposure. In this case, the first peak occurs before the wood ignites, and the second after its charring. The disadvantage of the study is the consideration of only two features of GasMas HUYa: the rate of heat release and smoke. However, in [4, 5], there are no proposals for using the identified features of heat release and smoke for EDF. The use of C images for detecting smoke and fire is discussed in [6]. It is noted that DIck based on C images requires the use of complex algorithms for color analysis of smoke and flames based on machine learning algorithms. At the same time, the objective complexity and diversity of real F significantly reduces the quality of HUYa under real conditions based on C images. For visualization in poor visibility conditions, it is proposed to use C images in the infrared range [7]. The disadvantages of using C images [6, 7] include the need to use complex image processing algorithms, as well as high requirements for the speed and memory capacity of computing tools. This leads to a significant increase in cost and a decrease in the efficiency of DIcks based on such Cs. Another disadvantage of using such Cs for DIcks is the presence of false DIcks. To overcome the shortcomings of using C images, it is proposed in [8] to use neural networks. However, their use involves a learning procedure that requires some time. The application of the deep neural network learning method is discussed in [9]. Moreover, such training is based a priori on a large number of scenarios of various Fs, 3D conditions, illumination, quantitative assessment of the characteristics of the HUY GasMas, etc. To overcome this drawback, in [10] it is proposed to use the empirical cumulative distribution function of the recurrence of GasMas HUY increments measured by traditional S. It is shown that such a function can be used as a sign of Z. However, the disadvantage of this approach is the complexity and inconvenience of its use in practice. In this case, the method and indicators of DIck quality based on the use of the cumulative function are not considered.

Thus, the use of C measurements of GasMas HUY and modern procedures for statistical processing of measurements makes it possible to carry out operational HUY in premises. However, the known procedures for processing measurements of the GasMas HUY from the corresponding Cs turn out to be difficult to implement and do not allow determining the quality indicators of GasMas. In this regard, the unsolved part of the problem under consideration is to devise constructive methods for HUY in real time for measuring the HUY of GasMas with an indication of the quality of DIcks.

3. The aim and objectives of the study

The goal is to devise a constructive method for the current detection of ignition in premises with a given quality indicator based on measurements of an arbitrary hazardous parameter of the gas environment in real time. Current detection of ignition with a given quality indicator will allow them to be quickly extinguished in order to prevent a fire in the premises.

To achieve the goal of our work, the following tasks were set:

– to perform a theoretical substantiation of the method for detecting fires in premises with specified quality indicators based on measuring the current values of an arbitrary hazardous parameter of the gas environment in the premises;

– to conduct laboratory experiments to test the proposed method when test materials ignite.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study is the selective average GasMas HUY during the ignition of materials. The main hypothesis assumes that the values of selective average GasMas HUYev have different values in the absence and presence of ignition of materials. The main simplification of the study is the use of a limited set of GasMas HUYev and materials that were ignited.

4. 2. The study materials

The research materials included output signals of D GasMas HUYa in the laboratory chamber and a sample (S) from these signals of a fixed size, corresponding to two general populations, defined by the absence and presence of test materials (TM) Z in the laboratory chamber (LaCha) [11]. Alcohol (burnout rate 33.0 kg m^{-2} s^{-1} 10^3, lower calorific value 13400 kJ kg^{-1}), paper (8.0 kg m^{-2} s^{-1} 103, 27200 kJ kg^{-}1) were used as TM for Z), as well as wood (14.0 kg m^{-2} s^{-1} 10^3, 13800 kJ kg^{-1}) and textiles (6.7 kg m^{-2} s^{-1} 10^3, 13800 kJ kg^{-1}). The main GasMas HUY, measured by traditional C in LaCha, were the concentration of CO, smoke density, and temperature. Temperature measurements were made with TPT-4 (Ukraine) S, smoke density – IPD-3.2 (Ukraine) S, and CO concentrations – Discovery (Switzerland) S. C were placed in the ceiling area of the LaCha, which is the most typical for HUYa [12]. It was believed that the features of the influence of TM Z on the considered GasMas HUY in the LaCha are identical to the influence in real premises.

4.3. The study methods

The main research methods were the sampling method and the method for testing statistical hypotheses. The measurements were made from two general sets of measurements of HUY in GasMas. The first corresponded to the reliable absence of material Z in LaCha. At the same time, this set turned out to be training. The second was determined by current measurements of GasMas HUY in a fixed observation interval moving in time, starting from the interval corresponding to normal conditions. This population was termed the control or test population. In this case, the control population could, with an unknown probability, be determined by both the absence and presence of material Z. Measurements of HUY of GasMas were carried out discretely in time with an interval of 0.1 s. From the GasMas HUY measurements corresponding to the specified general populations, S of a fixed size, including 30 measurements, were extracted. The specified size S ensured the representativeness of the sample means for the training and control populations, as well as the asymptotic approximation of the sample means to the Gaussian distribution. All measurements of each HUY GasMas were stored in computer memory for subsequent thematic processing. Using the calculated selective average HUY GasMas, the method of testing the null hypothesis at a given level of significance produced a current decision on the presence or absence of Z. During the laboratory study, the current HUY was used for TMs by forcing them to Z in the interval between 220 and 260 samples of GasMas HUY measurements. After each of the indicated TM Z, natural ventilation of LaCha was performed for 5–7 minutes.

5. Devising an ignition detection method based on current values of a hazardous gas environment parameter

5. 1. Theoretical justification of the ignition detection method

The EDF method plays a key role in providing early warning of Fs by recognizing the parameters of F materials. Fs pose a significant risk to both security and social progress. Fs pose a particular danger at nuclear power facilities [13]. This is due to the fact that radiation at these objects also leads to radioactive contamination of the objects themselves and the environment. Each stage of F and the corresponding maximum heat release rate significantly depend on many features of fire loads and materials of construction of the premises [14]. At the same time, fire safety of facility premises has the highest priority. The increasing complexity, variety, and configuration of fire loads in modern premises requires increasing the sensitivity and reliability of fire protection equipment. Any amount of material in the room is associated primarily with its influence on the parameters of GasMas. Among GasMas HUY that are characteristic of the early stage of F and are dangerous to humans, they usually include temperature, CO concentration, smoke density, as well as their derivatives. For this reason, the indicated GasMas HUYi are traditionally used as signs of F in modern fire alarm systems. However, the indicated HUYi can also be used for DIcks in order to prevent the occurrence of F. Let us assume that there is a S of a fixed size m from the measured values of an arbitrary GasMas HUY $x1$, $x2$,..., xm, where m=1, 2,..., m. Then complete information about the statistical properties of S will be contained in its sample distribution function $F(x)$. Using $F(x)$ in practice to characterize S usually turns out to be quite difficult. Therefore, instead of $F(x)$, its various sample moments are often considered [15]. The important and most frequently used are the first initial and second central sample moments, which characterize the position and dispersion of the sample distribution function $F(x)$. In mathematical and statistical terms, the problem of current DIck can be stated as a modified problem of testing the null hypothesis. This modification is that the null hypothesis corresponds to the general population of values of an arbitrary GasMas HUYa in the reliable absence of Z (training population), and the alternative hypothesis corresponds to the general population of values of an arbitrary GasMas HUYa in the unknown possible presence of Z (controlled population). In this case, the training population does not depend on time while the controlled population depends on the current time. Let S extracted from the training population be characterized by the sample distribution function $F1(x)$, and S extracted from the controlled population – by the sample distribution function $F2(x, t)$, where t is the current time. Then, in the case of the absence of Z, $F1(x)\approx F2(x, t)$, and in the case of Z, $F1(x)\approx F2(x, t)$. Similar conditions remain for the corresponding sample moments of the distributions $F1(x)$ and $F2(x, t)$. This means that the current HUYev method in the general case can be based on checking the homogeneity of various sample moments of the distributions $F1(x)$ and $F2(x, t)$. As sample moments of these distributions, we consider the corresponding moments of the first order (sample means). Let there be S of a fixed size $m1$ values of an arbitrary GasMas HUY $x(1)$, $x(2)$,..., $x(m)$, where m=1, 2,..., $m1$ from the training population. The training population corresponds to normal conditions for an arbitrary GasMas HUY indoors. For the current DIck, a second S is formed from a controlled general population of a fixed size $n2\leq m1$, where n=1, 2,..., $n2$ for the current time t, determined by the values of the same arbitrary GasMas HUY $x(t-1)$, $x(t-2)$,..., $x(t-n)$, where n=1, 2,..., $n2$. Since the proposed method for current DIck is based on checking the homogeneity of sample means for the distributions $F1(x)$ and $F2(x, t)$ in real time. This means that $S\,x(1), x(2),..., x(m)$ must precede or may coincide in time with $S\,x(t-1), x(t-2),..., x(t-n)$, where $t\geq n2$. The decision on the presence or absence of Z is made for the current time t. To increase the accuracy of the temporary localization of DIck under conditions of non-stationary GasMas HUY, it is advisable to reduce the size of $S\,m1$ and $n2$. However, in this case, errors of representativeness increase, and great mathematical difficulties arise in determining quantitative indicators of the quality of the current DIck [15]. Therefore, it is proposed to use the large sizes of *S* $m1$ and $n2$, which allow the sample moments of the first order for the considered HUYev to be considered asymptotically, having a Gaussian distribution. With increasing size of *S*, the degree of asymptotic approximation will melt, and the representativeness and accuracy of estimating the first-order sample moment will also increase [15].

Let us denote by $X1$ and $X2_t$ the sample means calculated from *S* $x(1), x(2),..., x(m)$ and $x(t-1), x(t-2),..., x(t-n)$, respectively:

$$X1=\sum_{i=1}^{m1} x(i)/m1, \tag{1}$$

$$X2_t=\text{if}\left(t\geq m1, \sum_{i=1}^{n2} x(t-i)/n2.0\right). \tag{2}$$

Let us assume that $X2_t$ at the current moment of time t differs from $X1$. At the same time, it remains unknown what the difference between $X1$ and $X2t$ should be at the current moment t in order for it to be considered significant and to assert that the true averages of the general populations under consideration really differ and are caused by materials Z. The value of the current difference $X1–X2_t$ can be studied using standard errors [15]. We shall assume that (1) and (2) follow asymptotic Gaussian distributions $\left(X1, s1/\sqrt{m1}\right)$ and $\left(X2_t, s2/\sqrt{n2}\right)$, respectively, in which $s1=\sqrt{\sum_{i=1}^{m1}\left(x(i)-X1\right)^2/m1}$, $s2_t=\sqrt{\sum_{i=1}^{n2}\left(x(t-i)-X2_{t-i}\right)^2/n2}$ define the standard errors (accuracies) of sample means for *S* $x(1), x(2),..., x(m)$ and $x(t-1), x(t-2),..., x(t-n)$. Then the difference $X1–X2_t$ will also follow an asymptotically Gaussian distribution $\left(X1-X2, \sqrt{s1^2/m1+s2^2/n2}\right)$ for all t, where $\sqrt{s1^2/m1+s2_t{}^2/n2}$ is the standard error of the current difference $X1–X2_t$. If we divide the value $X1–X2_t$ by $\sqrt{s1^2/m1+s2_t{}^2/n2}$, then we obtain a random variable that has an asymptotic Gaussian distribution ($X1–X2_t$, 1) with a unit standard error. This makes it possible to use the well-known tabulated Laplace function [15] to determine the quality indicators of the current DIck. Therefore, the current DIck method can be represented in the form of testing the null hypothesis (H_0), that the current difference $X1–X2_t$=0 against the alternative hypothesis (H_1), which $X1<X2_t$. To test these hypotheses, a left-sided critical region is constructed based on the requirement that the probability of the current normalized difference falling into this region, if the null hypothesis is true, is equal to the specified significance level α (probability of an artificial DIck). Considering that the normalized difference $X1–X2_t$ in the absence of Z is distributed symmetrically about zero, the desired critical point turns out to be symmetrical to the critical point for which the probability of exceeding the normalized difference is equal to the specified significance level α. Then the left-hand critical region for accepting the null hypothesis will be determined by the excess of the normalized difference $X1–X2_t$ of the value of the symmetric critical point with the opposite sign. If the opposite inequality holds, the null hypothesis is rejected and the alternative hypothesis H_1 (presence of Z) is accepted. With this rule for testing the hypotheses under consideration, the greatest power of the described method for current DIck will be ensured at a given significance level. The probability of the normalized current difference falling into the interval (0, ∞) if the null hypothesis is true, is 0.5. Therefore, the determination of the critical point for the left-sided critical region can be performed based on calculating the argument of the Laplace function. Taking this into account, the acceptance of an alternative hypothesis (DIck) based on the current difference $X1–X2_t$ will be determined in the case of an inequality of the following form:

$$\left(X1-X2_t\right)>-\Delta_k\cdot\sqrt{s1^2/m1+s2_t^2/n2}, \tag{3}$$

where Δ_k is the argument of the Laplace function corresponding to the value (0.5–α).

In this case, the acceptance of the null hypothesis (no DIck) taking into account inequality (3) will be determined by the following inequality:

$$\left(X1-X2_t\right)\leq-\Delta_k\cdot\sqrt{s1^2/m1+s2_t^2/n2}. \tag{4}$$

Taking into account expressions (3) and (4), the proposed method for current DIck can be represented as an equivalent inequality:

$$\left(X2_t-X1\right)>\Delta_k\cdot\sqrt{s1^2/m1+s2_t^2/n2}. \tag{5}$$

Thus, the proposed method for current DIck with a given significance level α, determined by inequality (5), will simultaneously provide the greatest power (probability of good DIck). In this case, a violation of inequality (5) will correspond to the decision about the absence of a current Z with a significance level α. To increase the sensitivity of the method to small changes in the current difference ($X2_t–X1$), it is necessary to reduce the value of the right side of inequality (5). For a given level of significance of the current DIck, this can be accomplished by increasing the size of the corresponding *S*. Usually in practice, when measuring the HUY of GasMas, it is convenient to select the size *S* from the condition that $m1=n2=p$. Taking this into account, a particular version of the current DIck method (5) can be represented as:

$$\left(X2_t-X1\right)>\Delta_k\cdot\sqrt{s1^2+s2_t^2}/\sqrt{p}. \tag{6}$$

In expression (6), the value of the size *I* p should provide a Gaussian approximation of the distribution for the current difference ($X2_t–X1$). For large sizes p *B*, the proposed method will hold even in the case when the distributions of GasMas HUYev values differ slightly from the Gaussian distribution. This is explained by the fact that the selective averages $X1$ and $X2_t$ are the sum of many terms, each of which has only a relatively small square deviation. Following [16], it can be shown that method (5) and (6) at a given significance level α provide the greatest power of the current DIck. This means that method (5) and (6) will provide the maximum probability of the correct current DIck based on the results of measuring the GasMas HUY of the room. However, for *S* from general populations whose distributions differ greatly from Gaussian, the Laplace functions will no longer provide a satisfactory approximation when calculating Δ_k. In this case, the value of Δ_k can be determined from the Benham-Chebyshev inequality [17], which gives an upper estimate of the probability of exceeding the standard deviation in the case of any type of distribution. Taking this into account, the value of Δ_k in (5) and (6) should be selected from the condition $\Delta_k \leq 1/\sqrt{\alpha}$. This condition allows the use of method (5) or its particular version (6) in the case of arbitrary distributions of real general populations and sizes Is that do not satisfy the condition of large Is.

5. 2. Experimental verification of ignition detection method

As a result of a laboratory experiment based on S from current measurements of CO concentration, smoke density, and GasMas temperature in LaCha at Z of alcohol, paper, wood chips, and textiles, a test of the proposed method of current DIck was performed (5). The results of experimental verification of the method are illustrated in Fig. 1–3 in the form of the dynamics of the difference $(X2_t - X1)$ (red curve) and the current threshold $\Delta_k \cdot \sqrt{s1^2 + s2_t^2} / \sqrt{p}$ (blue curve). The obtained data correspond to the specified significance level α=0.05 and size *Is* *p*=30 from measurements of the concentration of GasMas HUYa at TM Z.

In Fig. 1–3, the dynamics of the current threshold correspond to the value Δ_k, determined by the argument of the Laplace function, equal to $(0.5-\alpha)$.

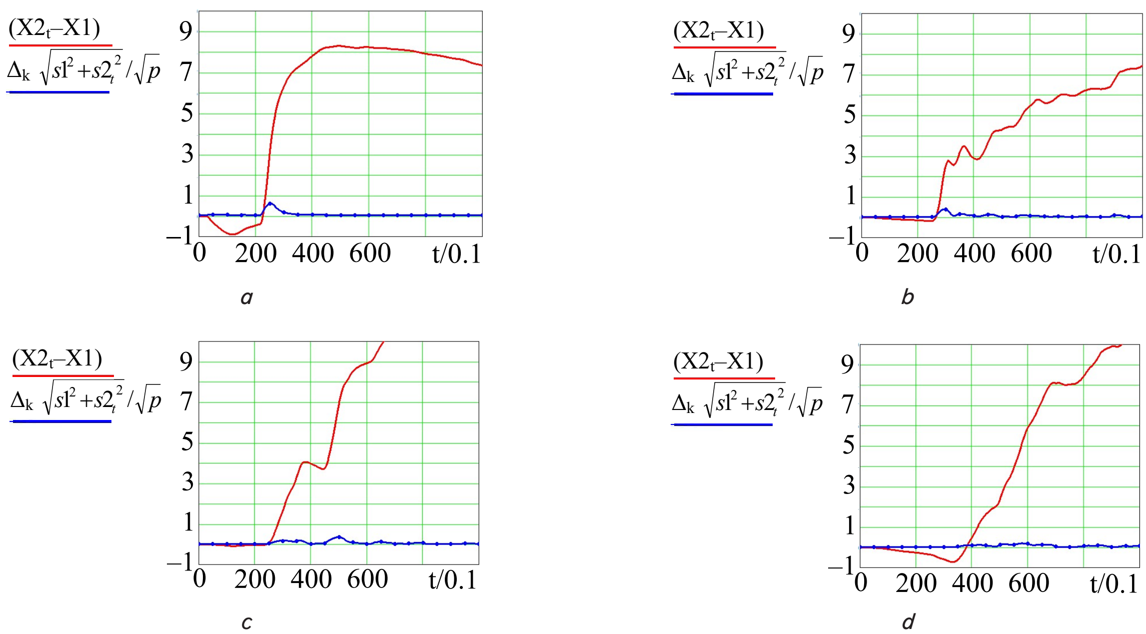

Fig. 1. Results of testing method (5) for CO concentration when igniting: *a* – alcohol; *b* – paper; *c* – wood shavings; *d* – textiles

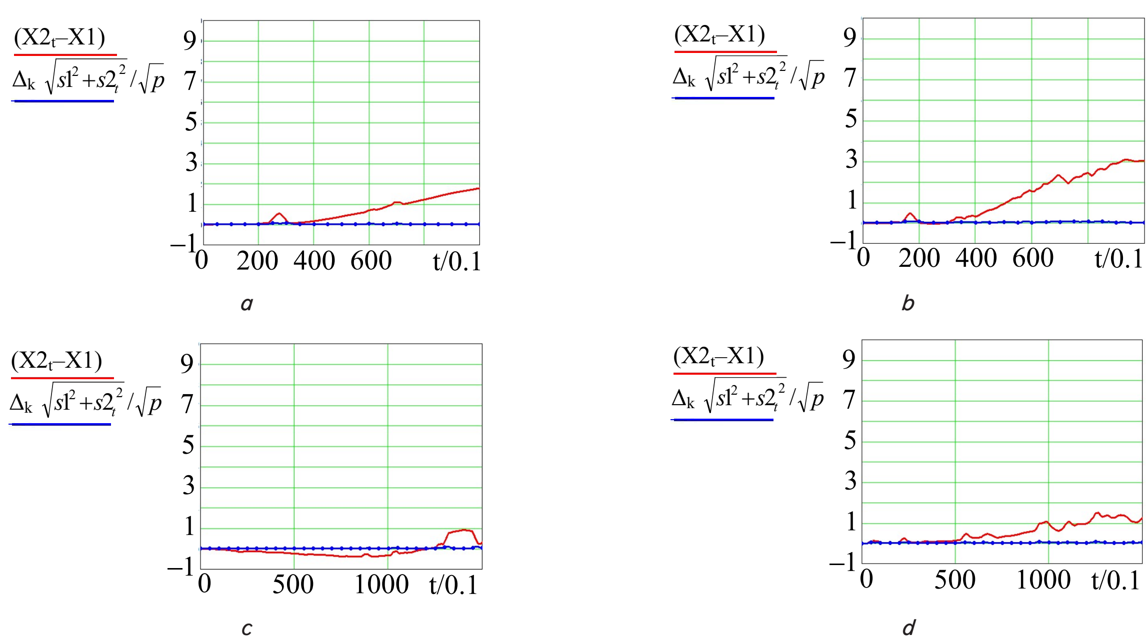

Fig. 2. Results of testing method (5) for smoke density when test materials ignite: *a* – alcohol; *b* – paper; *c* – wood shavings; *d* – textiles

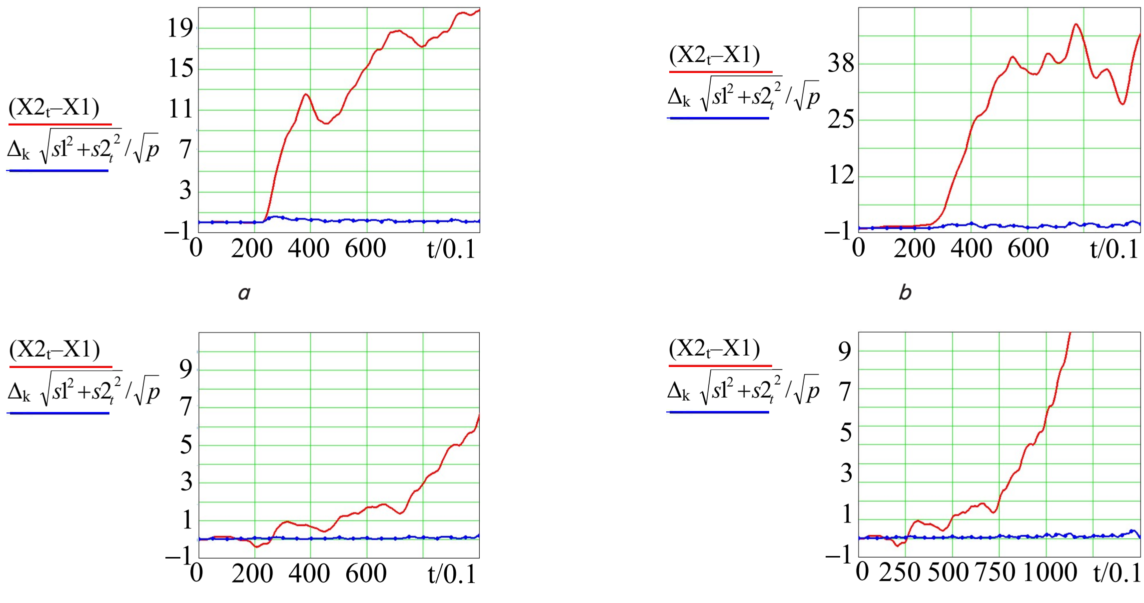

Fig. 3. Results of testing method (5) for the temperature at ignition of test materials:
a — alcohol; *b* — paper; *c* — wood shavings; *d* — textiles

6. Discussion of results of the ignition detection method test

Our results, shown in Fig. 1–3 can be explained by the fact that the current difference $X2_t$–$X1$, determined by the left side of (6), for the hazardous parameters under consideration at the moment of ignition of TMs increases. In this case, the value of the current difference exceeds or turns out to be lower than the corresponding value determined by the right-hand side of (6). This is explained by the fact that the magnitude of the current difference can be determined by both non-random and random factors. At a given significance level, an excess of the current difference indicates that it is caused not by random factors but by ignition. Shown in Fig. 1–3, the results correspond to size I p=30. For this size, the current selective average is a representative estimate for the general populations of CO concentration, smoke density, and GasMas temperature in LaCha. The dynamics of the value of the current difference $X2_t$–$X1$ for the studied GasMas HUYev and materials turns out to be different. This is explained by the unequal hidden complex physical-chemical mechanisms of the interaction of materials Z with GasMas products. For example, the current difference $X2_t$–$X1$ of CO concentration before Z (at the 200th count) and after Z (at the 500th count) at Z of alcohol, paper, wood shavings, and textiles are –0.459 and 8.296, –0.152 and 4.299, –0.027, respectively and 6.9, –0.262 and 2.361 (×10 ppm). Current differences $X2_t$–$X1$ for smoke density at similar reference moments are 0.043 and 0.391, 0.012 and 0.923, –0.139 and –0.235, 0.034 and 0.129 (dB/m), and for temperature – 0.01 and 10.635, 0.552 and 35.182, –0.375 and 1.124, 0.135 and 2.726 (°C), respectively.

By estimating the current difference $X2_t$–$X1$ of the HUY of GasMas based on a large I size, it was possible to circumvent the difficulties associated with unknown non-Gaussian distributions of DIck and represent the current difference within the framework of generalized accuracy. This made it possible to set a criterion for quantitative assessment of the quality of the decision on materials Z. This provides advantages of this study compared to the results reported in [18, 19]. In addition, the benefit of our study is the use of traditional S for GasMas HUY instead of S images. The obtained solutions in the form of DIck method (6) and the experimental results close the unsolved part of the problem under consideration in terms of developing a constructive method for the current DIck based on exceeding the difference $X2_t$–$X1$ of the selective average HUYev of GasMas for I of large size. This made it possible to determine quantitative indicators of the quality of our DIcks based on measurements of the HUY of GasMas, performed by traditional Ss. The results generally indicate that with TM Z in LaCha, the largest value of the current difference $X2_t$–$X1$ is characteristic of the temperature and concentration of CO in GasMas. The current difference for the smoke density turns out to be the smallest. This means that for real-big DIcks based on method (6), it is advisable to use temperature and CO concentration. The individual slight excesses of the current difference $X2_t$–$X1$ of the threshold (right side (6)) for smoke density and temperature (Fig. 2, 3) in the interval of reliable absence of Z are not fundamental since they can be eliminated by increasing the size of I over 30 counts or choosing the value Δ_k from the Benham-Chebyshev condition. A limitation of the study is the need to place traditional S for GasMas HUY in the ceiling area of a room or structure [20], where the maximum heterogeneity of GasMas HUYev occurs, caused by a convective jet with materials Z. A limitation of the study is related to the choice of a finite set of TMs and a limited number of GasMas HUYev. Further development of the study may be aimed at overcoming the noted drawback. In practice, research results can be used to detect ignitions in real time to prevent them from developing into an uncontrollable fire. Thus, the proposed method, taking into account a given level of significance, allows for real-time DIcks based on significant values of the current difference of sample means for a given size of I from GasMas HUY measurements.

7. Conclusions

1. A theoretical justification for the current ignition detection method has been carried out. The method is based on testing the null hypothesis. The null hypothesis is that the selective average of current measurements of an arbitrary hazardous parameter of the gaseous environment in the reliable absence of ignition coincides with the selective average of the same hazardous parameter at ignition. The alternative hypothesis assumes that the sample mean in the absence of ignition is less than the sample mean in the presence of ignition. In this case, the selective average of the hazardous parameter is determined over the interval of reliable absence of ignition (training selective average), and the selective average corresponding to the alternative hypothesis is calculated from a time-moving sample from the current measurements of the hazardous parameter (controlled selective average). In this case, the significance of the current difference between the controlled and training selective average allows for ignition detection in real time of observation of a hazardous parameter in the gaseous environment. The method makes it possible to set the significance level for the current difference and ensure maximum power.

2. Laboratory experiments were carried out to test the proposed method for detecting current ignition based on the current difference between selective averages of measured hazardous parameters in the gaseous environment corresponding to the control and training population. The test results showed that, at a given significance level, the method allows one to detect ongoing ignition of materials based on significant differences in sample means. The current difference in CO concentrations during and after ignition of alcohol, paper, wood chips, and textiles are -0.459 and 8.296, -0.152 and 4.299, -0.027 and 6.9, -0.262 and 2.3, respectively. It has been established that the current difference is significant and is not due to its random nature but to the appearance of a persistent effect in the form of ignition.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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