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DETECTION OF FIRE BY COMPARISON OF SAMPLING COEFFICIENTS OF VARIATION OF CURRENT MEASUREMENTS OF DANGEROUS PARAMETERS OF THE GAS ENVIRONMENT

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The object of this study is the selective coefficient of variation of dangerous parameters of the gas environment, which are caused by the general aggregates of reliable absence or occurrence of ignition of materials. The method of prompt detection of fires based on the comparison of the sample coefficients of variation of the hazardous parameters of the gas environment of the specified general populations and the verification for each moment of time of the result of the comparison of the sample coefficients of variation and exceeding the current threshold is theoretically substantiated. At the same time, the value of the current threshold is calculated taking into account the given probability of false detection of ignition and the current error of the result of comparing the sample coefficients of variation. This method makes it possible to ensure the maximum current probability of correct ignition detection. Experiments were conducted to verify the performance of the proposed method. The obtained results in general indicate the efficiency of the method. It was established that the result of the comparison of the sample coefficients of variation of the hazardous parameters of the gas environment, which correspond to the specified general populations for carbon monoxide at the time of ignition of alcohol, paper, wood, and textiles, is 0.47, 0.14, 0.2, and 0.001, respectively. For the temperature, the results of the comparison of the sample coefficients of variation during the ignition of similar materials are 0.12, 0.13, 0.015 and 0.045, respectively. At the same time, for prompt detection of fires based on the proposed method, it is necessary to preferably use the concentration of carbon monoxide and the temperature of the gas environment as dangerous parameters of the gas environment. The practical importance of the research is the use of selective coefficients of hazardous parameters of the gas environment for the detection of material fires in real time

Keywords: prompt detection of fires, sample coefficient of variation, dangerous parameters, gas environment

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1. Introduction

Any fire (F) is caused by ignition of materials (IM). IM is usually accompanied by varying amounts of heat release, a large number of hazardous chemical combustion products, and solid particles in the form of smoke. IM is usually dangerous due to its destructive effect on the objects where it occurs. IM is especially dangerous at energy facilities [1] and in the shipping industry. A disaster associated with IM on a ship poses a threat to transportation safety and can lead to the loss of the vessel, cargo damage, environmental pollution, human injury, and even loss of life. Fire early detection (FED) at the above-mentioned facilities allows for increasing the time for personnel evacuation or extinguishing IM, as well as reducing human casualties and material losses. Thus, a 10-minute delay in extinguishing a F in the engine room can potentially result in financial losses of \$200,000. At the same time, a 20-minute delay can lead to a tenfold increase in these losses [2]. Therefore, research on devising new FED methods at the stage of IM occurrence is relevant.

2. Literature review and problem statement

Traditionally, fire detection is carried out based on the use of sensors measuring hazardous parameters (HPs) of the gas environment (GE) of the premises of objects. This may be the concentration of CO, temperature, smoke density, and other parameters [3]. The main disadvantage of using sensors measuring GE HPs in traditional fire alarm systems is the impossibility of detecting fires with their help at the early stages of their origin – the stage of occurrence of IM. This is explained by the fact that fire detection is carried out based on the fact that the measured GE HP exceeds the corresponding threshold. The threshold value usually corresponds to the detection of the full stage of fire. In this case, while the value of the measured HP from the ignition material reaches the corresponding sensor and exceeds the set threshold, the fire can go from the initial stage of fire origin (stage IM) to subsequent stages, including the stage of full fire development. However, for the purpose of FED, it is necessary to take into account the peculiarity of the GE HP dynamics precisely at the initial stage of fire until the measured HP exceeds the set threshold. In [4] it is shown that at the SM stage the current dynamics of the GE HP is random and has a complex, individual, and nonlinear nature, depending on many parameters. Therefore, to identify the SM for the purpose of FED, it is possible to use the individual features of the complex dynamics of HP, complete information about which is contained in the corresponding sample distribution functions or their sample moments. Features of the real dynamics of wood combustion for three levels of the heat source (30, 40, and 50 $kW \cdot m^{-2}$) are studied in [5]. A random nature of the change in the average rate of heat release and smoke formation is noted over the entire range of exposure to the heat source. Characteristic peaks occur before the moment of ignition and after charring of wood. A disadvantage of [5] is the lack of research into the specific features of the current dynamics of the GE temperature during ignition and combustion of wood. Other types of ignition materials are not considered. The influence of the power of an external heat source on the dynamics of the GE temperature during wood combustion is studied in [6]. However, the study is limited to the relationship between the average dynamics of the GE temperature and the average intensity of wood combustion. Similar experimental studies for organic glass and cypress were performed in [7]. The limitations of the experimental studies [5–7] include the lack of data on the specific features of the current dynamics of the GE HP, as well as the dynamics of the sample moments of the HP distributions during IM. Research aimed at solving the problem of FED based on the use of non-traditional image sensors is actively developing. Such sensors allow remote measurement of the intensity of image pixels caused by IM [8]. Multilevel convolutional neural networks are widely used to solve the problems of identifying the onset of PF based on image sensors. The FED method based on the use of such networks is proposed in [9]. However, this method is based on a limited data set and has not been compared with any existing methods to verify its performance. In addition, all image sensor-based P detection systems and the implementation of these methods and technologies under real conditions have low performance due to the time spent on data collection, processing, and training [10]. As a result, the overall efficiency of FED under real conditions, characterized by the complexity and diversity of forms and types of occurrence of F, taking into account various obstructing factors, is significantly reduced. Detection of IM can also be carried out based on the use of traditional sensors for measuring the GE HP, applied in existing fire alarm systems. In this case, it is necessary to use various new approaches to processing the data of such sensors. For this purpose, in [11], the features of the current dynamics of the GE HP during IM in the spectral domain are studied. It was found that the phase spectrum contains characteristic signs of the appearance of IM in the frequency range above 0.2 Hz and can be used to detect IM. A disadvantage of considering the features of the current dynamics of the GE HP in the frequency domain should be considered the limitations inherent in the Fourier transform. In [12], the sample variance of the GE HP for two general populations is studied, caused by the absence and presence of IM. It is shown that the sample variances for the specified general populations have significant differences, which can be used as a sign of IM detection. However, the detection of IM in real time by measuring the GE HP based on the comparison of current sample variances and sample coefficients of variation of the GE HP dynamics is not considered in [12]. Thus, the problem of FED can be solved based on inexpensive traditional GE HP sensors, as well as expensive image sensors. At the same time, FED cannot be considered without prompt detection of IM. Existing fire alarm systems are not capable of implementing FED since they do not take into account the current statistical features of the GE HP dynamics at the stage of IM occurrence. At the same time, it is not possible to evaluate the quality indicators of detection of F and, accordingly, the operational detection of IM. The use of traditional sensors for FED is more preferable and does not require significant resources. In contrast, the use of more expensive image sensors for FED is associated with the use of complex image processing algorithms and also requires significant computing and Internet resources. This means that an effective approach to solving the FED problem is still missing. This approach should be optimal, have less implementation complexity, and provide the specified quality indicators of detection of IM. The unsolved part of the problem under consideration is the development of methods for the operational detection of IM based on traditional sensors that measure the current values of the HP of the GE, have insignificant complexity and provide an assessment of the quality of detection.

3. The aim and objectives of the study

The objective of our work is to devise a method for promptly detecting fires in rooms with a given quality of detection based on the use of a selective variation coefficient for current measurements. In this case, measurements should be performed by traditional sensors of an arbitrary hazardous parameter of the gas environment. This will make it possible to promptly detect fires in real time with a given quality.

To achieve the objective of the work, the following tasks were set:

– to justify the method for promptly detecting fires with a given quality based on selective variation coefficients of current measurements for an arbitrary hazardous parameter of the gas environment of rooms in the reliable absence and random occurrence of fire;

– to test the performance of the proposed method using the example of selective variation coefficients for current measurements of hazardous parameters of the gas environment in a laboratory chamber with forced ignition of test materials.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study was the dynamics of GE HP during the occurrence of IM in a non-hermetic room. The hypothesis of the study was the assumption that the value of the coefficient of variation of GE HP increases with IM compared to the case of its absence. The assumptions and simplifications accepted in the study consisted in the assumption of maintaining the nature of the dynamics of the main GE HP in the laboratory chamber and a real room during the ignition of selected test materials (TM) of ignition in the form of alcohol, paper, wood, and textiles.

4. 2. The study materials

Experimental study of material combustion is based on the fact that any ignition of a material in a room changes the physical parameters of the material and GE. At the initial stage, a convective flow arises above the TM source, transferring combustion products and heat to the ceiling of the room. As a result of this transfer, the parameters of the medium under the ceiling change. Usually, the transfer of excess enthalpy leads to an increase in temperature and turbulence of GE in the ceiling area. Therefore, the features of material combustion in a room can be studied by changing the GE parameters in the ceiling area. However, it is difficult to theoretically study the features of material combustion in a room by changing the turbulence characteristics of GE in the ceiling area. For this purpose, the features of material combustion in a room are studied experimentally. For this purpose, an experimental laboratory chamber was created that imitated an unsealed room of reduced dimensions. The chamber has dimensions of 0.81*0.81*0.80 m. Sensors measuring temperature, smoke density and CO concentration were placed in the ceiling area of the chamber above the source of material combustion. Such arrangement of measuring sensors in the chamber allowed us to study the features of combustion of materials in a jet stream of heat and gases from the combustion source in the ceiling zone. At present, combustion of materials in the room has not been studied enough, but it has practical significance for preventing F. As a sensor for measuring the temperature of GE, measuring the density of smoke and measuring the concentration of carbon monoxide, the TPT-4 sensor (Ukraine), the IPD-3.2 sensor (Ukraine), and the Discovery sensor (Switzerland) were used. The experiments were conducted under natural conditions. The chamber was not hermetically sealed. The measuring sensors had an accuracy class of 0.5. Alcohol, paper, wood, and textile were used as TM. All measurements of GE HP were conducted discretely in time with an interval of 0.1 s. The experimental design consisted of sequential ignition of each TM and measurement of temperature, CO concentration, and smoke density. TM ignition was performed at random moments in time (20–25 seconds after the start of the measurement). The measurement interval of the GE parameters in the chamber during the ignition of each TM was 30 s. After each measurement, natural ventilation of the chamber was carried out for 10 minutes.

4. 3. Research methods

The research methods were the sampling method and the method of testing statistical hypotheses. Samples were made from measurements of GE HPs. It was assumed that the measurements can be caused by both the absence and the presence of IM. This means that the measurements can belong to two general populations. In this case, the identification of IM can be considered within the framework of the task of testing two hypotheses. The first hypothesis (null hypothesis) means that the measurements belong to the general population of reliable absence of IM. It is proposed to call this general population the training population. The second hypothesis (alternative hypothesis) assumes that the measurements of GE HP belong to the general population of random occurrence of IM. Let us call this general population the control population. In this case, the control population, unlike the training population, is current. Samples of an arbitrary fixed size were extracted from the measurements of GE HPs. In this case, the sample size should ensure the representativeness of the sample variation coefficients for the general populations under consideration, as well as the asymptotic approximation of the distributions of the sample variation coefficients to the Gaussian distribution. The sample variation coefficients and the corresponding representativeness errors were determined in accordance with [13]. In [13], the specified properties for the sample variation coefficients will already be fulfilled for sample sizes exceeding 60 samples. During the verification of the method, the sample size was the same and amounted to 100 samples.

5. Devising a method for prompt detection of fires with a given quality

5. 1. Justification of a method for prompt detection of fires

FED is one of the important functions of the integrated systems for the protection of critical infrastructure facilities [14]. The FED function ensures a significant reduction in the risk of personnel loss and damage, as well as the complete destruction of facilities [15]. This function significantly reduces the negative impact of F on the environment [16]. Any IM causes various GE HPs. Therefore, the fact of occurrence of GE HP can be used as a sign of identifying IM. To determine the fact of occurrence of GE HP, we will use the current sample variation coefficient of measurements obtained by the corresponding sensors. Let there be results of measurement by the corresponding sensor of an arbitrary GE HP on the selected observation interval. In the case of discrete measurements, there is a sample of size h–$x1$, $x2$, ..., xk, where k=1, 2, ..., h. An exhaustive characteristic for such a sample is its sample distribution function $F(x)$ [13]. However, to solve applied problems, instead of $F(x)$, their various characteristics in the form of sample moments are often used.

The sample variation coefficient is considered as such a characteristic. It should be noted that in the general case, the sample can be conditioned by the general populations of both the absence of IM, the presence of IM, and their combination. In this case, the effect of the specified populations in time is unknown. In essence, the task of operational detection of IM is reduced to determining by the sample the moment in time when the general population corresponding to the absence of IM passes into the general population of the presence of IM. Since the measurements are made sequentially in time, the entire sample $x1$, $x2$, ..., xk is unknown to us. We will assume that a sample of a smaller size $g2 \ll h$ is known. In this case, for an arbitrary moment in time t, the sample $x(t-1)$, $x(t-2)$, ..., $x(t-g)$, where $g=1, 2,..., g2$, will be known. This means that there are two samples of size $g2$. Let the first sample be made from the general population of reliable absence of IM, and the second one is associated with the current time t and the unknown (tested) general population. In this case, we assume that the first sample corresponds to the hypothesis H_0, and the second one corresponds to the current (tested) hypothesis H_t. In this case, the problem of operational detection of IM can be formulated as a problem of testing the corresponding hypotheses H_t and H_0. We will test the hypotheses based on a comparison of the corresponding sample variation coefficients, which allow us to simultaneously estimate two distribution parameters, or more precisely, their ratio, position, and dispersion of the distributions of the measured GE HPs corresponding to the considered general populations. The sample size $g2$ should be made based on conflicting requirements – the accuracy of the moment of detection of IM and errors of representativeness to the general populations. In this case, with a decrease in the sample size $g2$, the errors of representativeness of the sample variation coefficients will increase, as well as the mathematical difficulties in quantitatively assessing the quality of detection of IM [13, 17]. Following [17], for an asymptotic approximation of the distribution of the sample variation coefficient to Gauss, occurs at sample sizes equal to 100 or more.

Taking this into account, the sample variation coefficients KB_0 and KB_t from the general populations corresponding to the hypotheses under consideration are determined by the relations:

$$KB_0 = \sqrt{\sum_{i=1}^{m1}\left(x(i)-X1\right)^2 / g2} \, / \, X1, \qquad (1)$$

$$KB_t = \text{if}\left(t \ge g2, \sqrt{\sum_{i=1}^{n2}\left(x(t-i)-X2_t\right)^2 / g2} \, / \, X2_t, 0\right), \qquad (2)$$

where $X1=\sum_{i=1}^{m1} x(i)/g2$ and $X2_t=\text{if}\left(t \ge g2, \sum_{i=1}^{n2} x(t-i)/g2, 0\right)$ are the sample means corresponding to hypotheses H_0 and H_t.

The proposed method is based on the study of the value of the current difference $KB_t-KB_0=KB_r$ within the framework of the theory of standard errors [17]. To do this, we normalize the value KB_r relative to $\sqrt{d1^2/g2+d2_t^2/g2}$. Here $d1^2$ and $d2_t^2$ are the variances of the standard errors corresponding to the sample variation coefficients determined by [17]. In this case, the normalized difference KB_r under the hypothesis H_0 will have an asymptotic Gaussian distribution with a zero mean and unit variance. This allows us to relatively simply evaluate the quality of the operational detection of IM at a given significance level. For this, it is sufficient to use the tabulated Laplace function. Taking this into account, the problem of the significance of the hypothesis H_0 or that the current difference $KB_r=0$ arises. In this case, if $KB_r<0$, which corresponds to $KB_0<KB_t$, then the decision is made in favor of the hypothesis H_t. Consequently, the operational detection of IM is reduced to determining the critical region in which the normalized difference KB_r, if the hypothesis H_0 is true, would be equal to the given significance level α. Since in the absence of IM the normalized difference KB_r has a symmetrical distribution with respect to zero, the sought critical point will be determined by the symmetrical critical point with the opposite sign. Taking this into account, the critical region for accepting the hypothesis H_0 will be determined by the excess of the normalized difference over the value of the symmetrical critical point with the opposite sign. If this condition is not met, the hypothesis H_0 is rejected and the hypothesis H_t is accepted. Such a rule will simultaneously provide the greatest power at a given level of α. Since the probability of the normalized current difference falling within the interval $(0, \infty)$ when the hypothesis H_0 is true is 0.5, the value of the critical point will be determined by the argument $r0$ of the Laplace function, for which it is equal to $(0.5-\alpha)$, taken with the opposite sign. The method for detecting IM can be represented as:

$$KB_r > r0\left(d1^2/g2+d2_t^2/g2\right)^{0.5}. \qquad (3)$$

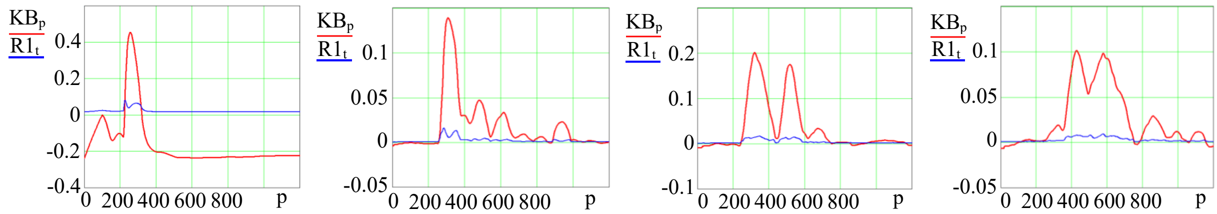
Rule (3) at an arbitrary moment t for a given significance level α (a given probability of false detection of IM) will simultaneously provide the greatest power (the probability of correct detection of IM). In this case, violation of rule (3) at the current moment t will mean that IM is absent. Let us introduce the value of the current threshold $R1_t = r0\left(d1^2/g2+d2_t^2/g2\right)^{0.5}$ for rule (3). Taking this into account, (3) will take its final form:

$$KB_r > R1_t. \qquad (4)$$

Following [17], for samples of large size $g2$, method (3) and (4) turns out to be valid even in the case when the measurements of GE HPs differ from the Gaussian distribution. In the case of arbitrary distributions of measurements for the general populations under consideration, the value of $r0$ in (3) can be chosen from the condition $r0 \le 1/\sqrt{\alpha}$. However, it should be noted that this statement is valid only for large sample sizes. In the case of small samples, a correction of the value of r0 is required, which for small samples is associated with significant computational difficulties.

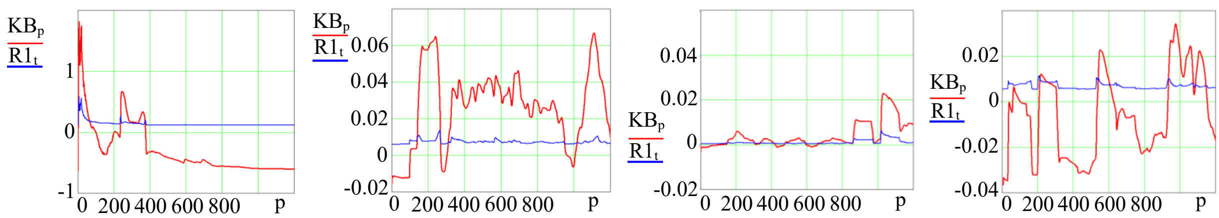
5. 2. Experimental verification of the method of operative detection of fires

Experimental verification of the proposed method of operative detection of IM (4) was carried out on the basis of the corresponding samples from current measurements of the concentration of CO, smoke density and temperature of GE in the laboratory chamber during the ignition of four types of TMs in the form of alcohol, paper, wood, and textile. Fig. 1–3 show dependences of the dynamics of the difference KB_r (red curves) and the threshold $R1_t$ (blue curves) at the significance level of $\alpha=0.05$ and the sample size $g2=100$ from the measurements of the specified GE HPs during the ignition of TMs in question. The numbers of current discrete measurements determined by integer values $p=[t/0.1]$ are indicated on the abscissa axis.



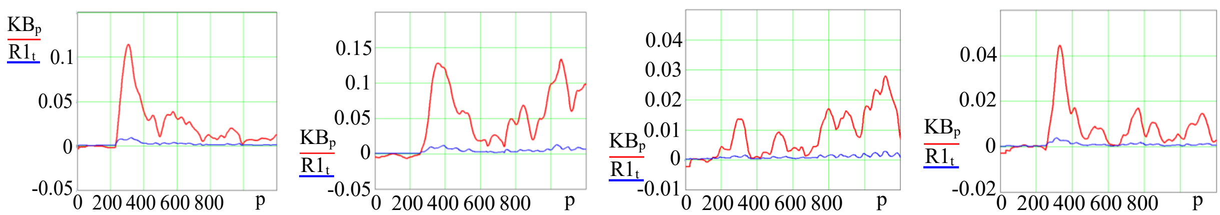
a *b* *c* *d*

Fig. 1. Dynamics of the difference between KB_r and the threshold $R1_t$ for CO concentration during ignition: *a* – alcohol; *b* – paper; *c* – wood; *d* – textile



a *b* *c* *d*

Fig. 2. Dynamics of the difference between KB_r and the threshold $R1_t$ for smoke density during ignition: *a* – alcohol; *b* – paper; *c* – wood; *d* – textile



a *b* *c* *d*

Fig. 3. Dynamics of the difference between KB_r and the threshold $R1_t$ for the ignition temperature: *a* – alcohol; *b* – paper; *c* – wood; *d* – textiles

The dynamics of the current threshold R_t (Fig. 1–3) correspond to the value r0, determined by the argument of the Laplace function, equal to (0.5–α) for the studied types of TMs. The TM ignition interval lay between the 220th and 260th count.

6. Discussion of results of the experimental verification of the method

Our results of the study indicate a solution to the problem of prompt reliable detection of IM based on the use of traditional sensors for measuring GE HPs. The main advantage of using the sample variation coefficient is that it can be used to compare the dynamics of different types of GE HPs that are formed as a result of IM. In general, the variation coefficient is a relative value that characterizes the average deviation of a random variable relative to its average value. Assuming that the deviation of a random variable is associated with noise, and its average value with a signal, we can interpret the value of the variation coefficient as the corresponding value of the noise/signal ratio. Then, the data in Fig. 1 show that the ignition of alcohol, paper, wood, and textiles leads to a sharp increase in the difference in KB_r concentration of CO GE or is equivalent to an increase in the noise/signal ratio, which is associated with an increase in the instability of the process of formation of the concentration of CO. From the data in Fig. 1 it is evident that the change in the difference KB_r for TMs has a different nature and magnitude. This indicates different properties of the IM process and the nature of the influence of IM on the stability of the concentration of CO. For example, the minimum time of instability of the CO concentration is typical for alcohol (Fig. 1, *a*). At the same time, the maximum value of the difference KB_r equal to 0.46 also occurs for alcohol. When paper, wood, and textiles ignite, the time of instability of the CO concentration is significantly longer. The maximum value of the difference KB_r at IM is 0.14, 0.2, and 0.1, respectively. Fig. 2 shows the dynamics of KB_r for smoke density and the corresponding dynamics of the threshold $K1_r$ in the case of TM ignition. In this case, IM also causes instability of smoke density. The maximum KB_r value for smoke density during IM is typical for alcohol and is approximately 0.6. For paper, wood, and textile, the maximum KB_r value is 0.06, 0.023, and 0.033, respectively. In this case, at the moment of paper ignition, the KB_r value of smoke density is 0.04 (Fig. 2, *b*). The first maximum KB_r of smoke density is explained by the source of paper ignition. A similar situation was observed at the moments of wood (Fig. 2, *c*) and textile (Fig. 2, *d*) ignition. However, in this case, the KB_r value of smoke density was lower and was 0.008 and 0.012, respectively. In this case, after the ignition of the above-mentioned TMs, insignificant random changes in KB_r of different signs were observed for a certain time. This means that during this time there were minor violations of the stability of smoke density. This state of smoke density was maintained until the moment of instability, corresponding to the KB_r value of smoke density equal to 0.01 and 0.022, respectively (Fig. 2, *c, d*). The indicated moments corresponded to approximately 850 count and 550 count. This means that until this time, after ignition, hidden complex physical and chemical processes of destruction occurred in wood and textiles with an insignificant violation of the stability of the smoke formation process. Fig. 3 shows the dynamics of the difference KB_r for temperature and the corresponding dynamics of the threshold $K1_r$ for the case of ignition of TM. According to the data presented, ignition of the specified TM causes the appearance of instability of the temperature of GE. The maximum value of KB_r for temperature at the moment of ignition is typical for paper and alcohol and is approximately 0.13 and 0.12, respectively. At the moment of ignition of wood and textile, the maximum value of the difference KB_r is 0.015 and 0.045, respectively. In this case, the dynamics of temperature instability after SM, characterized by the current difference KB_r, turn out to be random and depend on the type of material. This provides the advantages of this study compared to [18].

Thus, the experimental data presented in Fig. 1–3 generally indicate the ability of method (4) to promptly detect ignition of materials under study. In this case, the difference KB_r for the CO concentration and temperature at the onset of IM is the best. Thus, the difference KB_r in the CO concentration at the moment of ignition of alcohol is 0.47, paper – 0.14, wood – 0.2 and textile – 0.001. And the difference KB_r in the temperature at the moment of ignition of alcohol is 0.12, paper – 0.13, wood – 0.015 and textile – 0.045. This means that in practice, for the prompt detection of IM, in accordance with method (4), with a given probability of false alarm, it is advisable to consider the CO concentration and the GE temperature. The exception is highly flammable materials such as alcohol, for which the difference KB_r at the moment of IM is 0.5. A limitation of our study is the need to place GE HP meters in the ceiling zone of the protected volume [19], where significant fluctuations of GE HPs occur. As a disadvantage, it can be noted that the experimental verification of the proposed method was performed for a limited set of TMs and the main types of GE HPs during an IM in a laboratory chamber. Further development of the study is associated with overcoming this limitation and disadvantage. In practice, the results of our studies could be used for operational ID with a given probability of false alarm in order to timely extinguish IM and prevent them from developing into F.

7. Conclusions

1. We have substantiated a method for promptly detecting fires with a given error probability (significance or false alarm level) based on a comparison of current KB_r values for measured hazardous parameters of the gas environment in rooms. The method is based on a comparison of the sample variation coefficient of the hazardous parameter of the gas environment for the training and control populations. The training population corresponds to a reliable absence of fire (training hypothesis). The control population corresponds to the possible occurrence or non-occurrence of fire (control hypothesis). In this case, the control population, unlike the training population, depends on the current monitoring time of the hazardous parameter of the gas environment. For each population, the corresponding sample variation coefficient is determined. Based on the comparison of the specified sample variation coefficients, the current KB_r value is determined. The moment of fire detection is carried out upon the fact of KB_r exceeding the specified threshold, determined taking into account the specified significance level and the current error in determining the KB_r value. The method provides for setting different levels of significance (false alarm probability), while ensuring maximum power (probability of correct detection of fire). This ensures prompt detection of fires with specified quality indicators.

2. An experimental verification of the proposed method for prompt fire detection was conducted based on a comparison of sample variation coefficients for measurements of hazardous gas environment parameters corresponding to the training and control populations. Our results generally confirm the ability of the proposed method to promptly detect ignition of test materials. It was found that the KB_r value for carbon monoxide at the moment of alcohol ignition is 0.47, paper – 0.14, wood – 0.2, and textile – 0.001. For the temperature at the moment of alcohol ignition, the KB_r value is 0.12, paper – 0.13, wood – 0.015, and textile – 0.045. This means that for prompt fire detection, in accordance with the proposed method, it is advisable to use the carbon monoxide concentration and the gas environment temperature. It was confirmed that the proposed method at a significance level of 0.05 allows prompt fire detection with a fixed sample size of 100 readings from measurements of the studied hazardous gas environment parameters.

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, as well as 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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