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DETERMINING THE FEATURES OF HISTOGRAMS OF DANGEROUS PARAMETERS OF THE GAS ENVIRONMENT IN THE ABSENCE AND OCCURRENCE OF FIRE

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The object of research is histograms of the dynamics of dangerous parameters of the gas environment, the values of which are measured in real time at the intervals of absence and ignition of materials. The method of determining histograms during a typical selection of measurements is described. This method allows one to determine histograms for samples of an arbitrary position and the size of the data interval of measurements of the dynamics of dangerous parameters of the gas environment. On the basis of histograms on the intervals of the absence and occurrence of fires of test materials, indicators of their summary statistics can be determined. Laboratory experiments were conducted to study the features of the histograms of carbon monoxide concentration, smoke density, and temperature of the gas medium for intervals of reliable absence and appearance of ignition of materials in the form of alcohol and textiles. The results of the analysis of the histograms clearly show that the dynamics of the studied dangerous parameters at the indicated intervals differ from the Gaussian. At the same time, the histograms differ in shape, which depends on the type of ignition material and the corresponding dangerous parameter. Based on the features of the histograms of the dynamics of dangerous parameters on the intervals of the absence and appearance of fires of test materials, the simplest indicators of summary statistics in the form of the range, number, and position of the modes are determined. It was established that when alcohol ignites, the variation range of carbon monoxide concentration, smoke density, and gas temperature increases from 0.545, 0.068, and 0.161 to 7.121, 0.523, and 8.71, respectively. At the same time, the range of variation of these parameters during textile ignition increases from 0.182, 0.205, and 0.323 to 0.394, 0.386, and 2.903, respectively. The obtained results in aggregate or one by one can be used in practice for early detection of fires in order to prevent the occurrence of fires in premises

***Keywords:** fire hazard, dynamics histogram, dangerous parameters, gas environment, summary statistics, range of variation*

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1. Introduction

Security is a fundamental human need. At the same time, the condition for the stable development of humankind is to ensure the safety of the functioning of objects of the technical [1] and natural [2] spheres under the influence of various threats. The main threats can come from critical infrastructure objects [3, 4] in the form of various types of emergencies [5, 6]. At the same time, not only production is dangerous but also the processes associated with waste disposal [7]. With the expansion of areas of activity, dangers lie in wait for a person on the ground, in the air, and underground [8]. At the same time, active digitalization provoked new threats [9] related to the information sphere [10]. At the same time, under peacetime conditions, the greatest threat comes from fires [11]. Fires lead to death and injury to people [12], destruction of property and damage to industrial [13] and residential facilities [14]. In addition, combustion products, fire extinguishing agents, as well as by-products of fire equipment [15] negatively affect the environment, leading to pollution of water carriers [16], soils, and atmospheric air [17]. Worldwide fire statistics [18] indicate that the maximum number of deaths as a result of a fire falls on indoor fires (FI) (80 %). Reducing the fire hazard (FR) of premises involves an integrated approach, including preventive measures [19], early detection, and forecasting of fires [20]. The implementation of this integrated approach to reducing PO is aimed at different time frames [21]. So, for example, preventive measures [22] and PP forecasting [23] are aimed at reducing PO in the future and are not aimed at reducing it in real time (RT). However, it is known that the source of any SP is the current ignition of the material (SM) [24]. In this regard, the early detection of fires (EL) should be considered as an urgent problem of reducing the RO of premises in RT.

2. Literature review and problem statement

Work [25] considers the system of early detection of PP. Such a system is based on the video technology (VT) [26] of flame detection. It is noted that the early ignition of materials on the flame and their extinguishing is an effective way to reduce PO in the current time. However, it should be noted that not all materials develop a flame when ignited. In this case, hazardous parameters (OP) of the gaseous medium (HS) are not considered in [25]. The study of the degree of efficiency and accuracy of detection of SP based on BT was carried out in [24, 27]. It is noted that such technologies have the advantages of prompt detection of SM, visualization of the result, and intelligence. However, most real PPs are characterized by a long process of pyrolysis of the material without the appearance of a flame. At the same time, a large amount of smoke and other accompanying OPs will generally reduce the reliability of detection of PP. In addition, the use of VTs does not make it possible to detect SM under conditions of shading of the material, as well as non-visualized OP HS, for example, temperature or CO concentration. The disadvantage of using VTs for early detection of PP is their implementation complexity, dependence on many parameters, the need for significant computing resources, as well as susceptibility to HS disturbances. Ultimately, this limits their use for premises with the purpose of air intake in RT. In [28], the technology of early air intake is considered based on the characteristics of the dynamics of the OP HS in the premises. For the early OT, traditional first- and second-order statistics are used. Therefore, the VT based on these statistics is not possible in the case of nonlinearity of the OP HS dynamics, which is typical for most real conditions. Descriptive statistics for a typical selection of the dynamics of the OP HS is not studied in this case. VZ with the same type of sensors for measuring an arbitrary OP of the HS and the use of a neural network is considered in [29]. In this case, it is assumed that the arbitrary OP of the HS is constant but unknown and is observed against the background of additive Gaussian noise. However, such assumptions are accepted without proper justification and usually do not correspond to actual conditions. The implementation of the neural network in this case turns out to be complex and multi-parametric. Therefore, VZ based on [29] is difficult to implement in real time. Group processing of measurements of the OP HS by various types of sensors in fire alarm systems and the use of fuzzy logic principles for VZ are considered in [30]. However, the VT based on [29, 30] turns out to be difficult to implement, is limited to first- and second-order statistics and requires a large number of parameters to be specified. The use of statistics of the first and second order limits the possibilities of early air intake in RT based on the features of the nonlinear dynamics of the OP of the HS during the EM. Histograms of typical selection for the dynamics of the OP HS are not studied in this case. An experimental study of wood combustion was carried out in [31]. It has been established that during the combustion of wood there is an uneven release of heat in the HS. However, the influence of the released heat on the nature of the dynamics of the OP HS is not considered. The statistics of the dynamics of the OP HS is not studied in this case. A study of the dependence of the combustion intensity for three types of wood on the power of an external heat source of different power was carried out in [32]. At the same time, the results of the study are limited by the dependences between the average values of the power of the heat source and the intensity of wood burning. The influence of wood combustion on the statistics of the dynamics of the OP HS is not studied in [32]. Similar studies for organic glass and cypress were carried out in [33]. At the same time, [31–33] do not analyze the statistics of the dynamics of the OP HS, and there are also no studies of histograms of typical samples from the dynamics of the OP HS that are important for the OT and contain information about their statistical features. The use of recursive diagrams of the OP HS for the air intake is considered in [34]. Despite the high potential of recurrence diagrams, their application to VZ remains a rather difficult task. However, recurrence diagrams require a priori setting of the recurrence region, which depends on the nature of the current nonlinearity of the OP HS dynamics. Under real conditions, characterized by uncertainty, it is not possible to fulfill this requirement. Therefore, in [35], the adaptive adjustment of the recurrence region for the vector of arbitrary OP HS is considered for the purpose of early RT. However, the technologies [34, 35], despite the noted advantages and possibilities, turn out to be quite difficult to implement and do not allow EO in RT. The use of the structural function to identify hazardous impurities in the air [36] and overcome the a priori uncertainty of pollution [37] should be considered original. However, the structure function in [36, 37] is a second-order statistic. Therefore, this function turns out to be insensitive to the features of the nonlinear dynamics of the OP HS. In addition, the detection of impurities based on the structure function [36, 37] needs to determine the reliability of such detection. In this case, the sample distributions or their moments have known reliability estimates [38]. In [39], the amplitude and phase spectra of the OP HS dynamics are studied for typical samples belonging to the intervals of the absence and presence of PM in the laboratory chamber. It has been established that the features of the dynamics of the OP HS are manifested to a greater extent for the high-frequency components of the phase spectrum. However, the intensity of manifestation decreases with increasing frequency. The study of the features of the amplitude spectra of the third order (bispectra (BS)) for a typical selection from the dynamics of the OP HS was carried out in [40]. It has been experimentally confirmed that BSs are sensitive to the nonlinearity of the OP HS dynamics and can be used for air intake. However, the sensitivity of the BS significantly depends on the energy of the used OP HS. Therefore, in [41], the third-order phase spectrum or bicoherence (BC) is considered, which is invariant to the OP energy and contains similar information about the features of the nonlinear dynamics of the OP HS. At the same time, studies in [40, 41] are limited to the frequency domain. Despite the capabilities of BS and BC, EOs based on them require a preliminary transition from the time domain to the private one. The correct transition from the time domain to the quotient domain under conditions of non-stationarity and uncertainty in the dynamics of the OP HS seems to be problematic. In addition, the necessary localization of SM in RT based on BS and BC is not possible.

The analysis performed on the problem of early OT indicates the relevance of this issue, due to the lack of constructive approaches to its solution. This is explained by the complexity and diversity of the actual conditions of the air intake in the premises. To date, two main approaches are known. The first approach is based on the use of BT. The second approach is based on the change in the dynamics of the OP HS during SM. At the same time, a common problem for these approaches is the localization of the IS in the RE. It is known that the dynamics of the OP HS during PM is non-linear. The lack of an analysis of the statistics of the dynamics of the OP HS during SM significantly limits the possibilities of air intake in RT. It should be noted that the histogram of the sample of the dynamics of the OP HS with a typical selection of measurements should be considered the most informative for the VZ. Therefore, an unsolved part of the problem of air pollution in RT should be considered the study of the dynamics of the OP HS based on histograms for the typical selection of data characteristic of the absence and appearance of air pollution in the premises.

3. The aim and objectives of the study

The purpose of this work is to identify the features of histograms in the typical selection of measurements of the main hazardous parameters of the gaseous medium, which belongs to the intervals of reliable absence and occurrence of fires of materials in the room. The features of the histograms at the specified intervals can be used to detect fires for their prompt liquidation in order to prevent fires in the premises.

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

– to describe the method for determining histograms for samples of arbitrary position and size of the dynamics of hazardous parameters of the gaseous medium during material fires;

– to analyze histograms for samples of the dynamics of the main hazardous parameters of the gaseous medium at given fixed intervals of reliable absence and occurrence of fires for test materials with high and low mass burnout rates.

4. The study materials and methods

The object of our study was the histograms of samples of measurements of the dynamics of the main OP HS during the ignition of test materials (TM) in a laboratory chamber. The working hypothesis was that the histograms of the samples of measurements of the OP HS dynamics before and after the occurrence of the PM have distinctive features. At the same time, it was assumed that the distinctive features of the histograms of samples of measurements of the dynamics of the OP HS during SM in real rooms and in a laboratory chamber are isomorphic [42]. Alcohol and textiles were considered as HMs, which have different specific mass burnout rates (ethyl alcohol – 33 g/m^{2}s; staple fiber – 6.7 g/m^{2}s). It is known that the specific mass burnup rate of HMs largely affects the presence and properties of many OP HSs during PT [43]. This is explained by the fact that the amount of combustion products, including smoke and its temperature, is largely determined by the amount and type of substance that burned. Temperature, smoke density, and CO concentration were considered as the OP HS. At the same time, the measurement of the HS temperature in the chamber was performed by the TPT-4 sensor (Ukraine) [44], which is widely used in fire automation systems, the smoke density was measured by the IPD-3.2 sensor (Ukraine) [45], and the CO concentration was measured by the Discovery sensor (Switzerland) [46].

As the main research method, we used the method of determining histograms in a typical feature selection, adopted in mathematical statistics [47, 48]. As signs, the results of measurement by the corresponding sensors of the OP GS in the laboratory chamber during the ignition of the HM were used. Taking into account the requirements of [49, 50], the measurements of the OP HS were made by sensors located in the ceiling area of the laboratory chamber. Continuous OP HS were measured by sensors at discrete times with an interval of 0.1 s. The total number of discrete measurements for each OP over the entire observation interval was 500 readings. In the study of OD histograms, typical selection was used [51]. The essence of the typical selection was that two characteristic intervals were selected, determined by 100 discrete readings of measurements of the OP dynamics, in which there was a significant absence and, accordingly, PM took place. In this case, the SM was carried out approximately in the middle of the corresponding characteristic interval. The results of a typical selection of discrete measurements of the OP HS at characteristic intervals were stored in the computer memory to determine the corresponding histograms.

5. Revealing the features of histograms of hazardous parameters of the gaseous medium during ignition of materials

5. 1. Description of the method for determining histograms for samples of typical selection

When constructing a histogram, the range of values of a random variable is usually divided into a given number of segments, and then the number of data hits in each segment is counted [52]. Let the dynamics of an arbitrary OP HS on the observation interval $[0, T]$ be described by the realization $x(t)$, $t\in[0, T]$. Using an appropriate measurement sensor, this implementation is converted into a discrete sample $(x_0, x_1, x_2, ..., x_n)$ of measurements of size n. In this case, the value of n is determined by the time of the end of the observation interval $[0, T]$. We shall assume that $(x_0, x_1, x_2, ..., x_n)$ is a sample from the general population. Then, following the accepted typical selection, we divide this sample into characteristic parts. Let each part of the sample be determined by p discrete measurements. Then an arbitrary part of the original sample will be determined by the sample $(x_i, x_{i+1}, x_{i+2}, ..., x_{i+p})$, where i is the number of the initial discrete measurement of the arbitrary part of the sample. In this case, the following conditions must be satisfied for i: $0\leq i$ and $(p+i)\leq n$. It is known that for a sample of any size, its complete descriptive statistics is a histogram or its sample distribution [53]. Due to this feature, histograms are not as widely used in practice as compared to various sample measures characterizing approximate distributions [54]. However, from the point of view of studying the statistical features of the distribution of data in a sample, histograms contain the most complete information [55]. Let us represent an arbitrary sample $(x_i, x_{i+1}, x_{i+2}, ..., x_{i+p})$ of size p as the corresponding vector **data(i, p)**$=(x_i, x_{i+1}, x_{i+2}, ..., x_{i+p})^T$. Then, to determine the histogram of an arbitrary vector **data(i, p)**, you can use the special function **histogram(int, data(i, p))** in the Mathcad environment [56, 57]. Here, **int** is the number of intervals into which the entire range of the initial data of the **data(i, p)** vector is divided. The **histogram(int, data(i, p))** function returns 2 columns. The first column defines the average values of each of the **int** intervals, and the second one defines the frequencies of random data of the **data(i, p)** vector falling into each of the corresponding **int** intervals [58]. With this in mind, the histogram for an arbitrary data sample in the **data(i, p)** vector will be determined by the corresponding matrix:

$$\mathrm{HIST}=histogram(\mathrm{int}, data(i, p)), \qquad (1)$$

where HIST is a matrix in which the first column of $\mathrm{HIST}^{\langle 0\rangle}$ determines the average values of each of the **int** intervals, and the second column of $\mathrm{HIST}^{\langle 1\rangle}$ – the frequency of hitting the data contained in the **data(i, p)** vector in each of the corresponding **int** intervals. For graphical display of histograms, it is necessary to plot $\mathrm{HIST}^{\langle 0\rangle}$ along the abscissa axis, and $\mathrm{HIST}^{\langle 1\rangle}$ along the ordinate axis. Expression (1) allows us in the Mathcad environment to determine histograms for data samples characterized by an arbitrary beginning i and size p, forming the **data(i, p)** vector. An arbitrary choice of the beginning and size of the sample makes it easy to implement the method of typical selection of data from the general population [47]. In order to determine the typical part of the dynamics of the OP HS at SM, it is necessary to set the corresponding number i of the beginning of the typical part and its size p.

Thus, the use of relation (1) with a given number i of the beginning and a given size p allows us to select the typical part of the dynamics of an arbitrary OP HS of interest and determine the corresponding histogram for this typical part of the dynamics. By choosing different typical parts of the dynamics, and determining the corresponding histograms for them, it is possible to identify differences in the histograms of these typical parts. If the typical parts of the dynamics of OP GS correspond to the absence and presence of PM, then information about the differences in histograms revealed in this case can be used for early detection of PM.

5. 2. Analysis of histograms of the main hazardous parameters of the gaseous medium

As a result of the experiment, histograms (1) of the dynamics of CO concentration, smoke density, and HS temperature were determined during the SM of materials in the form of alcohol and textiles. To achieve this goal, two typical parts of the dynamics of these OPs of the same size $p=100$ were selected. In this case, the beginning for the first typical part i was determined by the number equal to the 100th discrete measurement (from the beginning of the observation), and for the second part, by the 200th count. This means that such typical parts of the dynamics do not overlap in time. The choice of these numbers for typical parts is due to the fact that the first part corresponds to the reliable absence of SM, and the second part corresponds to the reliable occurrence of SM in the laboratory chamber. The definition of histograms based on (1) is required for the specified typical parts of the dynamics to specify the number of intervals **int**. Since the CO concentration, smoke density, and HS temperature have different values, the determination of histograms was performed with the same number of intervals **int**, equal to 20.

Fig. 1 shows experimental histograms (1) of CO concentration, smoke density, and HS temperature for two typical parts of the dynamics, characteristic of the absence and appearance of alcohol ignition, respectively.

Fig. 2 shows similar experimental histograms (1) of the investigated OP HS for the same two typical parts of the dynamics, characteristic of the absence and appearance of textile fire, respectively.

In Fig. 1, along the coordinate axes, the values of the columns $\mathrm{HIST1}^{\langle 1\rangle}$ and $\mathrm{HIST1}^{\langle 0\rangle}$ of matrix (1), corresponding to the typical parts of the dynamics of the studied OP HS, are plotted in the case of alcohol ignition. At the same time, in Fig. 2, along the coordinate axes the values of columns $\mathrm{HIST4}^{\langle 1\rangle}$ and $\mathrm{HIST4}^{\langle 0\rangle}$ of matrix (1) are plotted – in the case of textile fire.

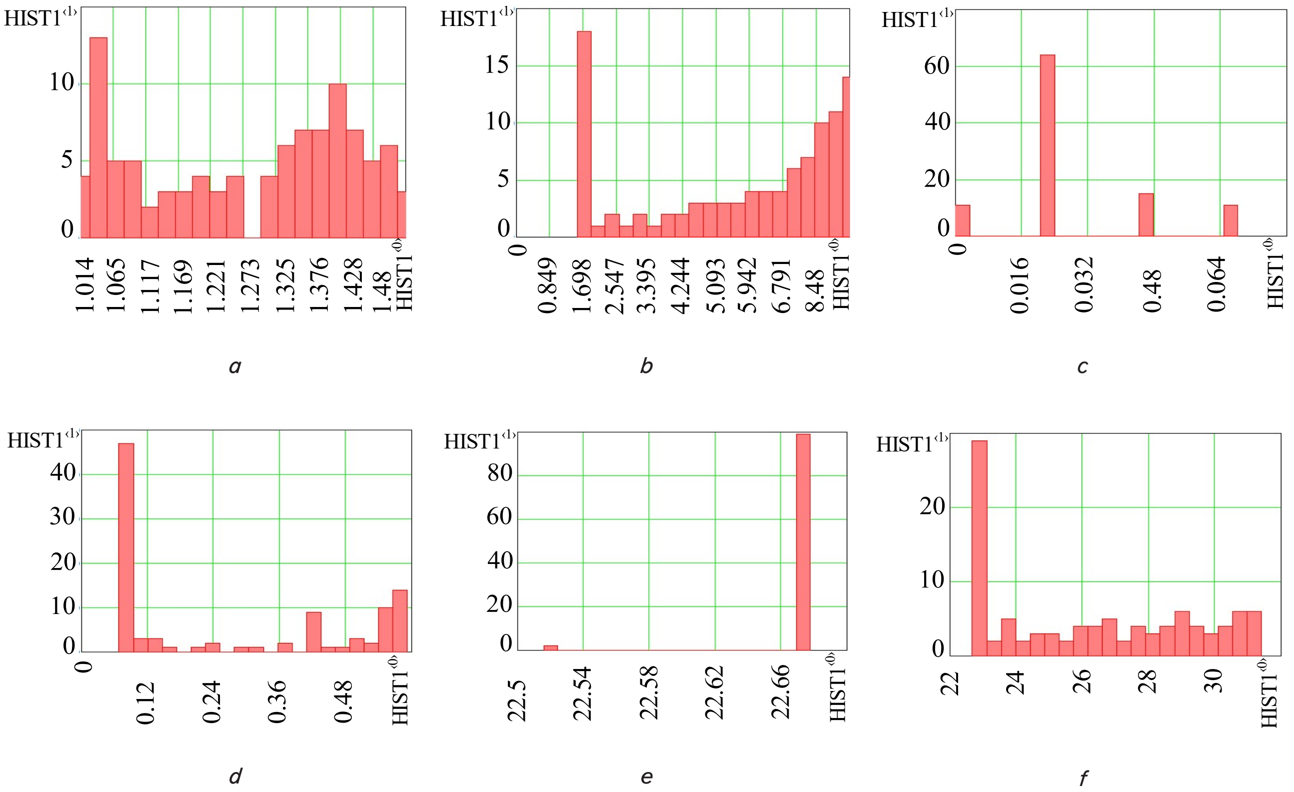

Fig. 1. Experimental histograms, respectively, of CO concentration, smoke density, and temperature in the case of alcohol ignition for two typical parts:
a, c, e — no ignition; *b, d, f* — the appearance of a fire

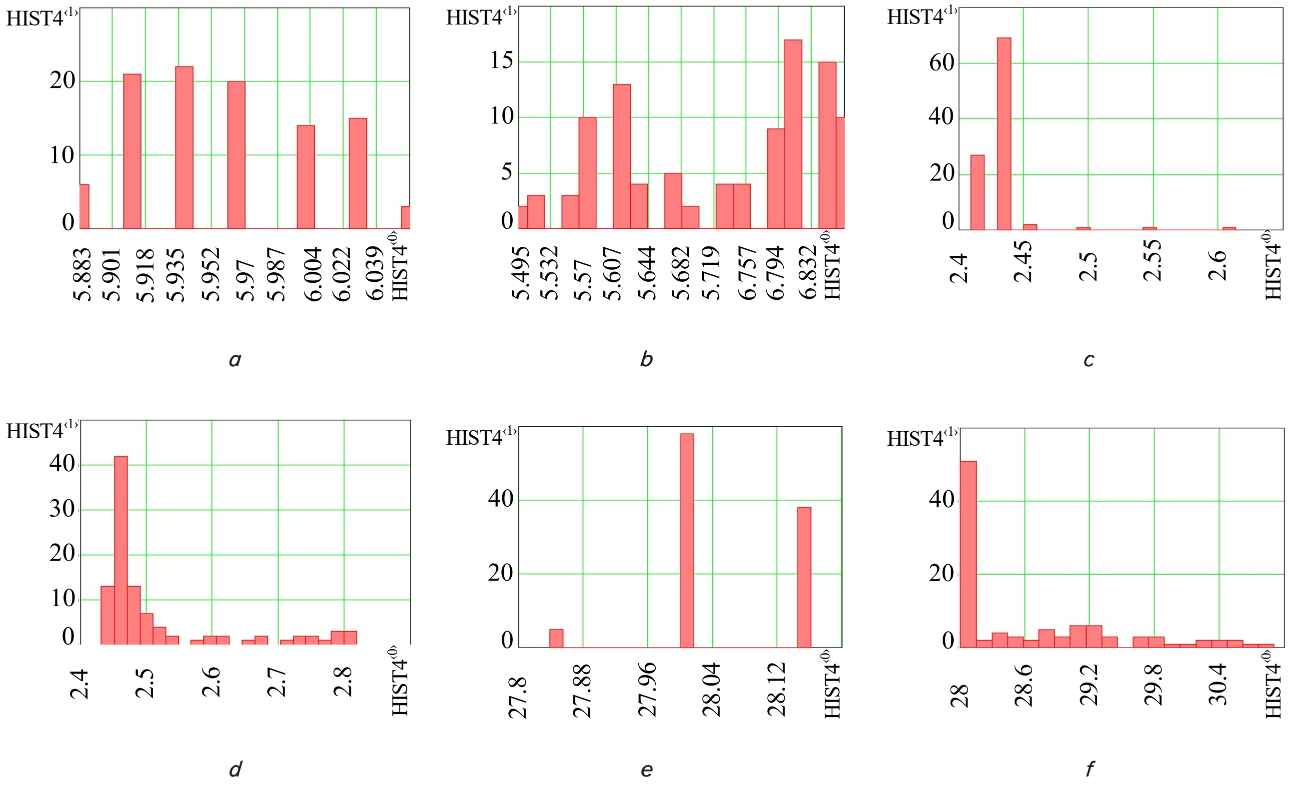

Fig. 1. Experimental histograms, respectively, of CO concentration, smoke density, and temperature in the case of alcohol ignition for two typical parts:
a, c, e — no ignition; *b, d, f* — the appearance of a fire

6. Discussion of the features of histograms of the main hazardous parameters of the gaseous medium

The analysis of histograms in Fig. 1, 2 for the CO concentration, smoke density, and HS temperature on the corresponding typical parts of the dynamics in the case of fire of alcohol and textiles reveals the heterogeneous nature of the change in the OD of the HS. This is explained by the differences in the complex mechanisms for the formation of the current values of the considered OP HS in the absence and occurrence of SM. In this case, the nature of the diagrams testifies on the whole to the nonlinearity of these complex mechanisms. This result coincides with modern ideas about the nonlinearity of the OP dynamics both before and after the appearance of the SM. The given histograms allow us, in the general case, to draw many conclusions important for practice.

First of all, it should be noted that the choice of a fixed number of intervals in determining the histograms, equal to 20, makes it possible to identify the features of their shape with a sufficient degree of detail. However, with a large number of intervals and a small range of variation of the discrete values of the OP HS, the histograms will contain intervals with a zero hit frequency (the shape of the histogram will be of a line character). Reducing the number of intervals in this case will lead to smoothing of the shape and masking of the features of the histogram. Thus, the histograms of CO concentration, smoke density, and HS temperature in the absence of alcohol ignition, shown in Fig. 1, *a, c, e*, are characterized by a different range of variation equal to 0.545, 0.068, and 0.161, respectively. In the event of an alcohol fire, the range of variation of the studied OP HS (Fig. 1, *b, d, f*) is 7.121, 0.523, and 8.71, respectively. At the same time, for the CO concentration, the histogram in the absence of alcohol ignition is characterized by two modes corresponding to the middle of the intervals of 1.041 and 1.423 and the number of values that fall into these intervals, equal to 13 and 10, respectively. In the case of alcohol ignition, the histogram of CO concentration is also characterized by two modes corresponding to the average values of the intervals 1.723 and 8.489 and the number of values falling into these intervals equal to 18 and 14, respectively. At the same time, for the smoke density, the histogram in the absence of alcohol ignition is characterized by the presence of one mode, which corresponds to the middle of the interval 0.022 and the number of measurements is 64. In the case of alcohol ignition, the histogram is also characterized by one mode, but corresponding to the middle of the interval 0.081 and the number of measurements is 47. For the HS temperature, the histogram in the absence of alcohol ignition, it is characterized by the presence of one mode, which corresponds to the middle of the interval 22.673 and the number of measurements 99. In the case of alcohol ignition, the histogram is also characterized by one mode, but corresponding to the middle of the interval 22.895 and the number of measurements 29 falling into this interval. At the same time, for intervals with average values exceeding 22.895, the number of measurements that fall into these intervals is nonzero and amounts to 2–6. For the histograms of the studied OP HSs in the absence of textile ignition, shown in Fig. 2, *a, c, e*, are characterized by different ranges of variation, equal to 0.182, 0.205, and 0.323, respectively. When a textile fire occurs, the range of variation of the OP GS (Fig. 2, *b, d, f*) is 0.394, 0.386, and 2.903, respectively. At the same time, the histogram of CO concentration in the absence of textile ignition is characterized by three main modes corresponding to the middle of the intervals 5.911, 5.938, and 5.965 and the number of CO concentration values – 21, 22, and 20, respectively. In the case of textile fire, the histogram of CO concentration is also characterized by three modes with average values of the intervals 5.613, 5.81, 5.849. The number of measurements falling within these intervals is 13, 17, and 15, respectively. At the same time, for the smoke density, the histogram in the absence of textile ignition is characterized by the presence of two modes that correspond to the middle of the intervals 2.414, 2.435 and the number of measurements 27 and 69. In the case of textile ignition, the histogram is characterized by one mode corresponding to the middle of the interval 2.461 and the number of measurements 42. The histogram in the absence of textile ignition is characterized by the presence of two modes that correspond to the middle of the intervals 28.008 and 28.153 and the number of measurements 58 and 38. In the case of alcohol ignition, the histogram is characterized by one mode corresponding to the middle of the interval 28.073 and the number of measurements 51. At the same time, for intervals whose average values exceed 28.073, the number of measurements that fall into these intervals is nonzero and amounts to 2–6.

The results described above testify to the differences in the shape of the histograms of the studied OP HSs in the absence and appearance of SM. The existing differences in the histograms in the case of fire of alcohol and textiles are consistent with the features of their burnout. It should be noted that histograms, having the most complete display of the properties of the random variables under study, represent a display in graphical form. Therefore, in practice, various sample statistics of distributions are usually used in the form of appropriate measures of the position of histograms, the spread of sample values, and the shape of histograms [59, 60]. The practical significance of the research is the fact that various numerical measures can be determined from histograms that characterize their position, scatter, and shape. The features of these measures for histograms of various symptom intervals of observation can be used to detect the onset of PM and prevent PP.

The limitations of this study include the consideration of only the simplest indicators of summary statistics in the form of the range, number and position of the modes of the histograms of the studied OP HS in the intervals of absence and appearance of SM. Therefore, this study can be developed in the direction of the study of other indicators of summary statistics. For example, measures of the form of histograms, which, following the results obtained, differ from the Gaussian form. The disadvantage of the study is the limited value of the typical interval of occurrence of SM. It was assumed that SM occurs approximately in the middle of this interval. This means that the OP histogram for this interval is determined by two different parts of the OP dynamics – the absence of EP and the beginning of its appearance. This disadvantage can be eliminated by choosing a smaller typical interval.

7. Conclusions

1. A method for determining histograms in a typical selection of measurements is described. This method makes it

possible to determine histograms for samples of an arbitrary position and size of measurement data for the dynamics of dangerous parameters of a gaseous medium. The method makes it possible to study the features of histograms in the typical selection of measurements of hazardous parameters of the gaseous medium in the absence and occurrence of fires of test materials. The practical significance of the conducted research is the fact that on the basis of histograms of measurements of the dynamics of dangerous parameters in the intervals of the absence and occurrence of fires of materials, their various quantitative indicators can be determined, for example, positions, dispersion, as well as the shape of histograms, which make it possible to solve applied problems of detecting the onset of fire and prevent fire in premises.

2. Laboratory experiments were carried out to identify the features of histograms of carbon monoxide concentration, smoke density, and temperature of the gaseous medium. The data of a typical selection, corresponding to the measurements of the dynamics of the indicated dangerous parameters of the gaseous medium at the intervals of the reliable absence and occurrence of fires of alcohol and textiles, were studied. The results indicate that the dynamics of the studied dangerous parameters on typical intervals is non-Gaussian. At the same time, the histograms of hazardous parameters corresponding to these intervals differ in shape, which depends on the type of ignition material and the type of hazardous parameter. On the basis of the revealed features of the histograms, the simplest indicators of the summary statistics of dangerous parameters in the form of a range, number and position of modes were determined. At the same time, it was found that when alcohol ignites, the range of variation of the corresponding dangerous parameters increases from 0.545, 0.068, and 0.161 to 7.121, 0.523, and 8.71, respectively. In this case, the range of variation of the indicated dangerous parameters of the gaseous medium during the ignition of textiles increases from 0.182, 0.205, and 0.323 to 0.394, 0.386, and 2.903, respectively.

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.

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