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REVEALING THE PECULIARITIES OF ASYMMETRY AND KURTOSIS COEFFICIENTS OF GAS MEDIUM PARAMETERS IN PREMISES DURING FIRE

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The object of the study is the coefficients of asymmetry and excess of the selective distribution of hazardous parameters of the gas environment during material fires. The practical importance of the research lies in the use of measures of asymmetry and kurtosis for early detection of fires. The measures of asymmetry and kurtosis for sampling the final size of an arbitrary dangerous parameter of the gas environment are substantiated. The proposed measures make it possible to investigate the peculiarities of the coefficients of asymmetry and kurtosis in relation to the selective distribution of an arbitrary dangerous parameter of the gas environment. At the same time, it becomes possible to numerically determine the degree of difference of the sample distributions of dangerous parameters from the Gaussian, as well as the features of such measures. Experiments were conducted to determine the degree of asymmetry and excess of dangerous parameters of the gas environment in the laboratory chamber at the intervals of the absence and presence of ignition of the test materials. The obtained results indicate that on the intervals of absence and presence of fires, the selective distributions of dangerous parameters of the gas environment differ from the Gaussian distribution. Distributions are complex and individual in nature. Features of measures of asymmetry and kurtosis depend on the type of ignition material. It was established that the maximum values of the modulus of increase in the degree of asymmetry are characteristic for the carbon monoxide concentration (2.939) during the ignition of paper, for the smoke density (3.098) during the ignition of textiles, as well as for the temperature during the ignition of alcohol (7.163) and wood (1.06). It was determined that the maximum values of the modulus of excess measure increase are characteristic for smoke density (4.678) when paper, wood (1.652) and textiles (28.932) ignite, as well as for temperature (49.377) when alcohol ignites

Keywords: world of asymmetry, world of excess, vibratory rozpodil, unsafe parameters, gaseous medium, burning material

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1. Introduction

The resistance of objects to threats is one of the most important modern problems. At the same time, man-made threats are associated with an adverse impact as a result of human activities [1], and natural ones – as a result of a threatening event, which is likely to have a negative impact on the population and habitat [2]. A special place is occupied by the issue of ensuring the sustainability of critical infrastructure [3, 4]. This is explained by the fact that such objects are themselves sources of threats and emergencies [5], and their activity is key for the existence of the state and the life of the population [6]. With the expansion of spheres of activity, danger lies in wait for a person on the ground, in the air, and underground [7]. At the same time, active digitalization provoked new threats [8] related to the information sphere. It should be noted that not only production is dangerous but also the processes associated with waste disposal [9]. Hazardous events associated with uncontrolled combustion occur most intensively [10]. Fires cause death and injury to people [11], lead to the destruction and damage of industrial [12] and residential facilities [13, 14]. Combustion products, fire extinguishing agents, as well as by-products of fire equipment [15] negatively affect the environment, causing pollution of water bodies [16], soils, and atmospheric air [17]. An analysis of statistical data on fires in the developed countries of the world indicates that the majority of fires are characteristic of three types of objects: residential, public, and industrial [18]. The largest number of fires occurs in residential buildings (55 %). At the same time, the greatest material damage (45 %) is caused by fires at industrial and residential (35 %) facilities. At the same time, the maximum loss of life occurs during fires in residential buildings (80 %). Regardless of the types of objects, fires occur most often in premises [19]. The priority direction of fire counteraction is based on preventive technologies [20], early detection [21], and fire forecasting [22]. Since the source of any fire is the ignition (IGN) of materials, it is possible to counteract fires only by timely detection of materials IGN and preventing their transition to a fire [23]. In this regard, the detection of fires (DF) should be considered as one of the urgent problems of our time.

2. Literature review and problem statement

Papers [24, 25] describe preventive technologies and technologies for predicting the dynamics of dangerous parameters (DDP) of a gaseous medium (GM), aimed at preventing the occurrence of IGN in the long term. Therefore, they are not applicable for solving the problem of the current DF (in real time). The difficulty of the current DF is due to the complexity and individual nature (uncertainty, non-stationarity, and non-linearity) of the real GM DDP at indoor IGN. Paper [26] proposes and studies a technology that makes it possible to overcome only the uncertainty and non-stationarity of a real GM DDP. At the same time, this technology is limited to considering the moments of distributions of the GM DDP not higher than the second order. This means that this technology is not suitable in the case of non-linear GM DDP. At the same time, the statistics of GM DDP above the second order, which characterize the nonlinearity, are not considered and are not studied. In [27], it is proposed to overcome the non-stationarity of GM DDP at IGN based on the technology of group processing of data from a plurality of sensors of the same type and the implementation of the network principle. The technology of batch processing of data from many different types of sensors is studied in [28]. However, technologies [27, 28] are limited to traditional statistics of no higher than the second order, which are not able to identify the features of the nonlinear nature of GM DDP, which are necessary for the current DF. The results of an experimental study of the combustion of three types of wood (two coniferous and one hardwood) for three levels of thermal radiation of 30, 40, and 50 kW·m^{-2} are reported in [29]. A linear relationship between the average heat release rate and radiation intensity was found, as well as the presence of two peaks in the heat release rate of samples from the beginning to the end of irradiation. At the same time, two strong smoke processes were established, one before ignition, and the other after the end of charring. However, at the same time, the effect of heat release and smoke of GM and their dynamics during ignition of the combustion of wood samples was not studied. The effect of wood combustion intensity on the temperature dynamics of GM was studied in [30]. However, the results are limited to the study of the average dynamics of GM temperature on the average combustion intensity. Similar studies for organic glass and cypress were carried out in [31]. However, in [29–31] there are no results of studying sample distributions or their characteristics for hazardous parameters (HP) of GM, which contain important information for DF about their nonlinear dynamics. For example, there are no studies on the features of the asymmetry and kurtosis of sample distributions of GM DDP at IGN. In [32], a DF technology was proposed based on recurrent diagrams of a nonlinear GM DDP for 3 materials. However, this technology requires setting two characteristic parameters depending on the characteristics of the dynamics. Under conditions of uncertainty in dynamics, it is proposed in [33] to use the technology of adaptive recurrent diagrams, which requires only setting an admissible cone for uncertain dynamics. However, the technologies [32, 33], despite the ability to reveal the features of a nonlinear GM DDP, turn out to be quite complex. At the same time, in [32, 33], there is no information about simpler technologies based on the use of sample distributions of GM DDP or their moments of order higher than the second. For example, there are no studies into the features of the sample coefficients of asymmetry and kurtosis of the sample distributions of GM DDP at IGN indoors. Work [34] considers the technology of DF based on the use of features of the autocorrelation relationship of GM DDP. The use of the structural function of GM DDP for DF is considered in [35]. Work [36] considers the technology of DF based on the use of the uncertainty function of GM DDP. At the same time, these technologies [34–36] are limited to the use of information contained only in the moments of distributions not higher than the second order. Features of the distribution moments of GM DDP above the second order (for example, the coefficients of asymmetry and kurtosis) under the conditions of a complex and nonlinear GM DDP are not considered. In [37], the possibilities of DF are studied on the basis of the peculiarities of the behavior of cross-correlations between different HPs of GM. However, correlations, being moments of the second order of distributions, make it possible to reveal features of only a linear relationship. In this case, the moments of the third and fourth order, which reveal the features of the nonlinear connection, are not studied. Work [38] examines the features of the amplitude spectra of the third order for GM DDP. It has been established that the amplitude spectra of the third order make it possible to reveal the features of the nonlinear relationship between the frequency components in the spectrum of GM DDP, which can be used for DF. However, the efficiency of DF based on this technology [38] significantly depends on the energy of HP GM. In this regard, in [39], the DF technology is proposed based on the features of bicoherence (BC), which is invariant to the energy of HP GM. However, studies in [38, 39] are limited to the selective estimation of the bispectrum (BS). In this case, the classical BS estimate is determined by averaging the sample BS estimate over the ensemble of implementations [40, 41]. Therefore, BC [39] will differ from the BC determined by [40, 41]. A comparison of these BCs was made in [42]. It has been established that BCs based on averaging a sample estimate of BS over an ensemble of implementations have the greatest potential for DFs. In addition, DF technologies based on BS and BC [38, 39, 42] turn out to be complex and are limited only to the frequency domain. The possibilities of identifying the features of an individual nonlinear GM DDP in the time domain are not considered. Despite the wide possibilities of using BS and BC [38, 39, 42] to identify the features of a complex GM DDP, DF technologies based on them are based on the transition from the time domain to the private domain. In this case, it is problematic to carry out a correct transition to the frequency domain under conditions of nonstationarity and uncertainty of DDP. Therefore, there is a practical need to study the features of high-order statistics of sample distributions of GM DDP. In this regard, the unsolved part of the problem is the study of the features of the coefficients of asymmetry and the kurtosis of the distributions of non-linear GM DDP at IGN.

3. The aim and objectives of the study

The purpose of this seminal work is to reveal the features of the coefficients of asymmetry and kurtosis of the distributions of dangerous parameters of the gaseous medium in the intervals of the absence of ignition and the occurrence of ignition of materials. The features of asymmetry coefficients and kurtosis of distributions of dangerous parameters of the gaseous medium at the time intervals of the absence and occurrence of ignition of materials are of practical interest for the early detection of fires to prevent the development of a fire in premises.

To accomplish the aim, the following tasks have been set:

– to perform a theoretical substantiation of the measure of asymmetry and kurtosis of distributions for arbitrary dangerous parameters of the gaseous medium on a fixed observation time interval;

– to conduct laboratory experiments to determine the measures of asymmetry and kurtosis under conditions of absence and onset of ignition.

4. The study materials and methods

4. 1. The study materials

The object of our study was the measures of asymmetry and kurtosis of the distributions of GM HP in the laboratory chamber at the intervals of the absence and occurrence of E for a set of test materials (TM). The working hypothesis assumed the difference between the measures of asymmetry and kurtosis of GM HP distributions in the intervals of the absence and occurrence of HMs. It was assumed that the nature and properties of GM DDP at IGN in real rooms turned out to be identical to the experimental dynamics in a laboratory chamber [38, 43]. Alcohol, paper, wood, and textiles were chosen as TMs. The studied GM HP were temperature, smoke density, and CO concentration. The GM temperature was measured with a TPT-4 sensor (Ukraine) [44], smoke density was measured with an IPD-3.2 sensor (Ukraine) [45], and CO concentration was measured with a Discovery sensor (Switzerland) [46].

4. 2. The study methods

The research method was a selective method for estimating the measures of asymmetry and kurtosis of the distributions of random dynamics of HP of GM according to the current measurements of HP in a laboratory chamber during the ignition of test materials. The measurements of HP of GM [47] were carried out by sensors located in the upper region of the laboratory chamber [48]. Measurements of HP GS were made discretely in time with an interval of 0.1 s. The total number of discrete measurements of the dynamics of each GM HP was 300 discrete readings. To identify the features of the measures of asymmetry and kurtosis of the distributions of the random dynamics of GM HP, two characteristic intervals were identified, corresponding to the significant absence and presence of ignition of the corresponding materials. The interval of absence of IGN corresponded to discrete measurements from 100 to 200 readings, and the interval of reliable IGN corresponded to discrete measurements from 200 to 300 readings. During the IGN study of each of the TMs were made approximately in the middle between 200 and 300 readings. The results of discrete measurements of GM HP were stored in the computer memory for their subsequent processing. At the start of the study, IGN of alcohols was started first, followed by paper, wood, and textiles. After IGN of each of these materials, the chamber was naturally ventilated for 5–7 minutes. It was assumed that the natural ventilation of the chamber made it possible to restore the state of GM HP after the corresponding HM. The method for processing discrete measurements implied nonparametric estimation of distribution moments [49].

5. Study of sample coefficients of asymmetry and kurtosis of hazardous parameters of the gaseous medium

5. 1. Theoretical substantiation of the measure of skewness and kurtosis

Let the implementation of an arbitrary HP x GM be observed on a given time interval. In this case, the result of the observation is represented as an independent sample $(x_1, x_2, ..., x_n)$ of a fixed size n. The probability density $w_1(x)$ of each sample value belongs to the nonparametric family W. In this case, the sample moment of the kth order will be determined by the arithmetic mean of the kth powers of the sample values:

$$m_k^* = \sum_{i=1}^{n} x_i^k / n, \text{ where } k = 1, 2, \dots. \qquad (1)$$

It follows from the law of large numbers [50] that the sampling moment (1) converges in probability to the corresponding distribution moment. A sufficient condition for the applicability of the law of large numbers in this case is the existence of a finite distribution moment of order 2k. It should be noted that the sample moments (1) are random variables while the distribution moments are constant numbers.

Along with statistics (1), the central sampling moment of the kth order is used:

$$\mu_k^* = \sum_{i=1}^{n} \left(x_i - m_k^* \right)^k / n, \text{ where } k = 2,3,,.... \tag{2}$$

Sample moment (2) for large samples is an unbiased and efficient estimate of the central moment of the k-th order of the distribution. It should be noted that the sample moments (1) and (2) with significant sample sizes are unbiased and efficient estimates of the corresponding moments, and under the condition $n \to \infty$ they are also consistent and asymptotically normal. However, it is known that the most complete characteristic of the sample (x_1, x_2, ..., x_n) of GM HP is not the moments but the sampling distribution [51]. At the same time, in the practice of identifying sample features, sampling distribution is inconvenient since it is a visual assessment. Therefore, various numerical indicators of distributions are more often used in the form of corresponding sample moments [52]. In order to identify the features of the distributions of GM HP at IGN, we will assume that the distributions, following [37–39], are non-Gaussian and belong to the nonparametric family W. Taking into account that the form of the distributions of GM HP is not a priori known to identify their features in the sample, we can use the moments (1) and (2) of order k=1, 2, 3, 4. The first and second moments characterize the mean and variance of sample distributions. These moments fully describe only Gaussian distributions. To identify features of distributions that differ from Gauss, the coefficients of skewness and kurtosis are used. Therefore, for an arbitrary sample (x_1, x_2, ..., x_n) of fixed size GM HP, the sample skewness coefficient will be determined by the expression:

$$As = \left(\sum_{i=1}^{n} \left(\left(x_i - m_k^* \right) \right)^3 / n \right) \Bigg/ \left(\sum_{i=1}^{n} \left(\left(x_i - m_k^* \right)^2 / n \right)^{3/2}. \tag{3}$$

In this case, the sample kurtosis coefficient for the sample (x_1, x_2, ..., x_n) will be determined:

$$Es = \left[\left(\sum_{i=1}^{n} \left(x_i - m_k^* \right)^4 / n \right) \Bigg/ \left(\sum_{i=1}^{n} \left(x_i - m_k^* \right)^2 / n \right)^2 \right] - 3. \tag{4}$$

It should be noted that the skewness and kurtosis measures defined by (3) and (4) in the case of an arbitrary sample (x_1, x_2, ..., x_n) from the family W of Gaussian distributions will be equal to zero. If the samples (x_1, x_2, ..., x_n) belong to distributions from the family W of non-Gaussian distributions, then measures (3) and (4) will be nonzero. The advantage of measures (3) and (4) is that they not only allow one to numerically characterize the degree of difference between the sample distribution and the Gaussian one but also indicate the sign of this difference. The sign carries additional information about the features of data distributions in the studied samples. At the same time, the absolute value of the measure makes it possible to judge both the degree of belonging of the samples (x_1, x_2, ..., x_n) to the family of Gaussian distributions, and to identify the features of non-Gaussian distributions for different samples of GM HP. Since measures (3) and (4) are random, their accuracy will be determined by the respective variances. Based on the generalized Chebyshev inequality, the variances of the skewness measures (3) and kurtosis (4) will be determined respectively [53]:

$$D((As)) = 6(n-1) / \left[(n+1)(n+3) \right], \tag{5}$$

$$D(Es) = 24n(n-2)(n-3) / \left[(n+1)^2 (n+3)(n+5) \right]. \tag{6}$$

It follows from relations (5) and (6) that the variances of the sample skewness and kurtosis coefficients depend only on the sample size n (x_1, x_2, ..., x_n). For example, in the case under consideration, for a sample size of n=100, $D(As)$=0.057 and $D(Es)$=0.207. In this case, the standard deviation for the measure (3) will be determined as $\sigma A = \sqrt{D(As)} \approx 0.24$ and for the measure (4) $\sigma E = \sqrt{D(Es)} \approx 0.52$. To make a decision about the hypotheses, a certain standard of procedure has been developed. Typically, decision making is based on the significance level α. The significance level is understood as the probability of erroneous rejection of the null hypothesis. Significance levels α=0.05 and α=0.01 are commonly used. These levels correspond to the acceptable error probabilities of rejecting the null hypothesis no higher than 5 % or 1 %. Let us introduce for measures (3) and (4) the corresponding significance levels α_A and α_E. Then, based on the generalized Chebyshev inequality and expressions (5) and (6), we obtain the following inequalities for the significance of measures (3) and (4), taking into account the given level:

$$|As| < \sqrt{D(As) / (1 - \alpha_A)} = \sigma A / \sqrt{1 - \alpha_A}, \tag{7}$$

$$|Es| < \sqrt{D(Es) / (1 - \alpha_E)} = \sigma E / \sqrt{1 - \alpha\ }. \tag{8}$$

In a particular case, for a sample of size n=100 and equal significance levels α_A=α_E=0.05, conditions (7) and (8) take the following form:

$$|As| < 0.245, \tag{9}$$

$$|Es| < 0.491. \tag{10}$$

If for measures (3) and (4) the corresponding conditions (7) to (10) are satisfied, then it is assumed that the values of the measures turn out to be insignificant and a decision is made in favor of the considered null hypothesis at a given level of significance. Otherwise, the null hypothesis with the given level of significance is rejected.

Thus, measures (3) and (4) allow us to study the features of the skewness and kurtosis coefficients that characterize the sample distribution for an arbitrary GM HP at different observation intervals. At the same time, inequalities (7) and (8) for an arbitrary sample size and significance level make it possible to determine the limits of the values of measures at which they turn out to be insignificant. This makes it possible to quantify the degree of difference between the sample distributions of the GM HP from the Gaussian distribution. For a Gaussian distribution, the values of the skewness and kurtosis measures are equal to zero. If the sample distributions have small values of the skewness and kurtosis measures, then we can assume that the sample distribution is close to Gaussian. At the same time, significant values of measures – will indicate significant differences in the sample distribution from Gaussian. Therefore, this technique allows us to study the features of measures of asymmetry and kurtosis for samples of GM HP of various sizes at arbitrary intervals of observation and to judge the features of the corresponding sample distributions without determining them. At the same time, observation intervals can be selected with a reliable absence and reliable IGN of materials.

5. 2. Determination of measures of asymmetry and kurtosis in the absence and onset of ignition

As a result of a laboratory study, measures of the asymmetry of GM HP (CO concentration, smoke density, and temperature) were determined at the intervals of the absence (T0) and the beginning of IGN (T1) of alcohol, paper, wood, and textiles (Table 1). Table 2 gives the measures of the kurtosis of GM HP on the intervals of absence (T0) and the beginning of IGN (T1) of the above TMs.

Table 1

Measures of asymmetry of hazardous parameters of the gaseous medium

No. of entry	GM HP/interval	Alcohol	Paper	Wood	Textile
1	CO/T0	–0.24	3.804	–0.169	0.211
2	CO/T1	–0.617	0.865	0.662	–0.37
3	|Δ CO|	0.377	2.939	0.831	0.570
4	S/T0	0.838	0.764	–0.694	4.842
5	S/T1	0.368	1.885	–1.237	1.744
6	|Δ S|	0.470	1.121	0.543	3.098
7	T/T0	–6.998	2.007	–0.964	–0.117
8	T/T1	0.165	1.271	0.103	1.075
9	|ΔT|	7.163	0.736	1.067	1.192

Table 2

Measures of kurtosis of hazardous parameters of the gaseous environment

No. of entry	GM HP/interval	Alcohol	Paper	Wood	Textile
1	CO/T0	–1.363	–0.968	–1.515	–0.912
2	CO/T1	–1.129	–1.011	–1.076	–1.35
3	|Δ CO|	0.234	0.043	0.439	0.438
4	S/T0	0.452	–1.208	–0.234	30.677
5	S/T1	–1.705	3.47	1.418	1.745
6	|Δ S|	2.157	4.678	1.652	28.932
7	T/T0	47.919	2.068	–0.08	–0.641
8	T/T1	–1.458	0.499	–1.627	0.057
9	|ΔT|	49.377	1.569	1.547	0.698

In Tables 1, 2, the rows of values of absolute increments of measures of asymmetry and kurtosis, respectively, for GM HP at the intervals of absence and beginning of TM IGN are highlighted in yellow. In red – the maximum values of the absolute increments of the measures of asymmetry and kurtosis for each GM HP and TM. In green – the values of the measures of asymmetry and kurtosis for the studied GM HP, satisfying the conditions of significance (9) and (10), respectively.

6. Discussion of results of the study of measures of asymmetry and kurtosis

The measure of skewness usually characterizes the skewness of the frequencies of occurrence of data in the sample that are above and below the mean value. A positive value of the measure of asymmetry indicates that values above the mean are more common. The negative value of the measure of asymmetry indicates that there are more data, the values of which are less than the average. With a measure of skewness of zero, data values that are greater than the mean and less than the mean occur equally frequently.

It follows from Table 1 that the sample distributions of CO concentration, smoke density, and GM temperature in the interval of absence of HM IGN differ from Gaussian. The measures of asymmetry turn out to be different for different IGN of HPs and TMs. Thus, for example, the measure of asymmetry for the concentration of CO in the interval of the absence of IGN of alcohol, paper, wood, and textiles is –0.234, 3.804, –0.169, and 0.211, respectively. For smoke density – 0.838, +0.764, –0.694, and +4.842, and for temperature, respectively, –6.998, +2.007, –0.964, and –0.117. Following (9), the HP sample distribution differs from the Gaussian distribution with a significance level of 0.05. This means that in the IGN absence interval, the sample distributions of dangerous parameters with a significance level of 0.05 differ from Gaussian. With TM IGN, the initial values of the measure of asymmetry change. The sign and magnitude of the measures, which depend on the type of TM IGN and GM HP, change. So, for example, at alcohol IGN, the measure of asymmetry for the CO concentration has a negative increment of 0.234, which does not change sign and remains negative. For smoke density, the measure of asymmetry is characterized by a large negative increment (0.47), which does not change sign and remains positive. For temperature, the measure of asymmetry has a positive increment of 7.163, which changes sign and becomes positive. At paper IGN, the measure of the asymmetry of the CO concentration has a negative increment of 2.939, which does not change sign, and remains positive. In this case, the smoke density asymmetry measure is characterized by a positive increment of 1.21, which does not change sign, and remains positive. For temperature, the measure of asymmetry is characterized by a negative increment of 0.736, which does not change sign, and remains positive. The noted features of the measure of asymmetry of GM HP in TM IGN (Table 1) indicate that the sample distributions of the corresponding HP are different from the Gaussian distribution and are more complex and individual. In this case, a decrease in the value of the asymmetry measure and a change in its sign indicate the loss of stability of the corresponding GM HP at TM IGN. The loss of stability of HP of GM is explained by the appearance of a characteristic fluctuating asymmetry of HP [54]. Therefore, the occurrence of such an asymmetry in the sample of GM HP can be considered as a sign of IGN. For the accepted level of significance (9), asymmetry measures in the absence of Z characterize the instability of CO concentration values before IGN of alcohol, wood, and textiles. A similar situation occurs for smoke density (before IGN of textiles) and temperature (before IGN of textiles, alcohol, and wood). These features of the measure of asymmetry are marked in green in Table 1. The maximum absolute increments of asymmetry measures at Z are highlighted in red. The maximum increments are characteristic for the concentration of CO (2.939) at IGN of paper, for the smoke density (3.098) at IGN of textiles, and also for the temperature at IGN of alcohol (7.163) and wood (1.067). At the same time, the maximum absolute increments of the BP asymmetry measure can also be considered as a sign of the appearance of a fault.

The measure of kurtosis, in contrast to the measure of asymmetry, characterizes the presence of both large deviations of data from the mean, as well as the frequency of their occurrence. In this case, the sign of the measure of kurtosis indicates the side of the data deviations from the mean. It follows from Table 2 that the kurtosis measure for CO concentration, smoke density, and temperature for all TMs in the intervals of absence and presence of IGN is nonzero. This means that the studied HPs are characterized by the presence of asymmetric deviations of the data from the mean value. The smaller the negative measure of kurtosis, the lower the frequency of occurrence of smaller deviations of the HP data from the mean value. For example, for the intervals of absence and presence of TM, the kurtosis measure for CO concentration is negative and takes values from –0.912 to –1.36 for all TMs. In the IGN absence interval, the kurtosis measures for smoke density are 0.452, –1.208, –0.234, and 30.667, respectively. This means that before TM IGN the smoke density is characterized by deviations of the data from the mean value, which are different in magnitude and sign. So, before alcohol IGN, the values of smoke density are characterized by insignificant excesses of the average value, and before textiles IGN – by significant excesses of the average. Before paper and wood IGN, the smoke density values are characterized by the predominance of lower values relative to the average value. At TM IGN, the sign and magnitude of the measure of kurtosis generally change. This means that 3 TM leads to a change in the nature of the distribution of large and small values relative to the mean value. The latter causes a corresponding change in the original sample distributions. For the temperature before IGN of alcohol, paper, wood, and textiles, the values of the kurtosis measure are 47.919, 2.068, –0.08, –0.641, respectively. This means that in the temperature values in the absence of IGN of alcohol and paper, values above the average prevail, and for textiles, values below the average prevail. In this case, wood is characterized by an approximately symmetrical deviation of values relative to the mean. At alcohol IGN, the kurtosis measure for smoke density and temperature changes sign, while for CO concentration it remains negative. This means that alcohol IGN causes a decrease in the kurtosis measure, which indicates the loss of the initial stability of CO concentration values. In the case of paper IGN, the change in the measure of kurtosis for each HP is different. The greatest changes in the kurtosis measure are characteristic of the smoke density. With wood IGN, the change in the measure of kurtosis for the concentration of CO is similar to the case of paper IGN. For smoke density and temperature, changes in the measure of kurtosis at TM IGN are accompanied by a change in the sign of the measure. The greatest change in the kurtosis measure at wood IGN is typical for smoke density. With textiles IGN, the change in the kurtosis measure for the concentration of CO is similar to the case of wood IGN. For smoke, the change in the measure of kurtosis is maximal (28.932). The measure of kurtosis for temperature changes sign, and the sign change of the value of the measure indicates a short-term loss of temperature stability. The indicated features of changes in the measures of asymmetry and kurtosis can be considered as signs of DF. The maximum values of the increment modulus of the measure of asymmetry are typical for the CO concentration (2.939) at paper IGN, the smoke density (3.098) at textiles IGN, and the temperature at IGN of alcohol (7.163) and wood (1.067). The maximum values of the incremental modulus of the kurtosis measure are typical for the density of smoke (4.678) at paper IGN, wood (1.652) and textiles (28.932), as well as for the temperature (49.377) when alcohol is ignited.

Thus, the proposed approach allows, for an arbitrary sample size and any HP of GM, taking into account a given level of significance, to identify sample distributions of HP different from the Gaussian based on their measures of asymmetry and kurtosis. The results obtained do not contradict the data of [32, 38, 39]. Their peculiarity lies in the approach to determining the measures of asymmetry and kurtosis instead of the unknown sample distributions of GM HP and the corresponding critical boundaries, taking into account the size of the samples and the significance of the null hypotheses, as well as the measures of the corresponding GM HP in the laboratory chamber in the absence and presence of fires of materials. This makes it possible to solve the gap associated with identifying the features of the asymmetry coefficients and kurtosis of the distributions of the nonlinear GM DDP at IGN. At the same time, the limitation of the study is associated with a finite set of GM HP in the laboratory chamber. The disadvantage of the study is the impossibility of using the described approach if it is necessary to solve the problem of temporal localization of materials IGN. The elimination of this shortcoming is associated with a modification of the approach to determining the measures of asymmetry and kurtosis. The development of research can be carried out in the directions of overcoming the noted limitations and shortcomings.

7. Conclusions

1. A theoretical substantiation of the measures of asymmetry and kurtosis for sampling the finite size of an arbitrary dangerous parameter of the gaseous medium is carried out. The conditions for the significance of such measures are determined, which, for an arbitrary sample size and significance level, make it possible to determine the boundaries of the values of the measures under which the values of the measures turn out to be insignificant. This has made it possible to study the features of the coefficients of asymmetry and kurtosis of the sample distribution for an arbitrary hazardous parameter of the gaseous medium at different observation intervals. Measures of skewness and kurtosis make it possible to numerically determine the degree of difference between the sample distributions of hazardous parameters of the gaseous medium from the Gaussian distribution, as well as the characteristic features of the appearance of changes in the data.

2. Laboratory experiments were carried out to determine the measures of asymmetry and kurtosis under conditions of absence and onset of ignition. The results obtained indicate that the hazardous parameters of the gaseous medium in the intervals of the absence and presence of fires have sample distributions that differ from Gaussian. At the same time, the distributions are complex and individual. Features of measures for sample distributions depend on the type of ignition material and measures of asymmetry and kurtosis of dangerous parameters of the gaseous medium in the interval without ignitions. It has been established with a significance level of 0.05 that the maximum values of the asymmetry measure increment modulus are typical for CO concentration (2.939) when paper is ignited, smoke density (3.098)

when textiles ignite, and temperature when alcohol (7.163) and wood (1.067) ignite. It has been determined that the maximum values of the kurtosis measure increment modulus are characteristic for the smoke density (4.678) when paper, wood (1.652), and textiles (28.932) are ignited, as well as for the temperature (49.377) when alcohol is ignited.

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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