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DYNAMICS OF SKEWNESS AND KURTOSIS OF DANGEROUS ENVIRONMENTAL PARAMETERS IN THE EVENT OF FIRE

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The object of this study is the dynamics of skewness and kurtosis of the selective distribution of dangerous parameters of the gas environment in the current time when materials are ignited. The theoretical substantiation of the methodology for determining the dynamics of skewness and kurtosis based on a sample of an arbitrary size of dangerous parameters of the gas medium moving in the current time of observation has been performed. Thresholds for current skewness and kurtosis are determined depending on sample size and null hypothesis significance levels. The procedure makes it possible to investigate the peculiarities of the dynamics of skewness and kurtosis and to identify moments of time for which alternative hypotheses (stability of parameter dynamics) are valid. Laboratory experiments were conducted to study the dynamics of skewness and kurtosis in terms of carbon monoxide concentration, smoke density, and the temperature of the gas environment during the ignition of alcohol and textiles. The results indicate that the investigated dangerous parameters are generally not Gaussian in the observation interval. It was found that the nature of the dynamics of measures of the current sample distributions of dangerous parameters depends on the type of ignition material and the dangerous parameter. It was established that in the absence of ignition, the dynamics of skewness and kurtosis of dangerous parameters is characterized by different directional skewness and kurtosis. In the event of ignition, the dynamics of skewness and kurtosis are fluctuating (from –4 to 18), which indicates the instability of the development of the dangerous parameter over time. The specified procedure creates an opportunity to detect the instability of the development of a dangerous parameter, which in practice makes it possible to detect the occurrence of fires (with a given reliability) in order to eliminate them and prevent the occurrence of a fire

Keywords: skewness, kurtosis, sampling distribution, dangerous parameters, gas environment, ignition

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1. Introduction

Safety is one of the basic human needs [1]. With the development of mankind, man-made security threats [2] have gradually become dominant over natural ones [3]. Moreover, man-made threats have become complex [4] and can affect a person not only directly but also disrupt the environment of human activity, reducing the comfort and quality of life, causing diseases and loss of material values [5]. In peacetime, the main sources of such threats should primarily be the objects of critical infrastructure [6]. In addition, most objects in the ecological, technical [7], and information sectors [8] are also recognized as potential sources of danger [9]. The greatest danger in terms of frequency of occurrence is represented by events associated with uncontrolled burning – fires (*Fs*) [10]. *Fs* represent a serious threat to people's lives [11], lead to the destruction or damage of industrial [12] and residential objects [13]. Hazardous combustion products, fire-extinguishing substances, as well as fire-fighting equipment [14] negatively affect the environment, simultaneously causing pollution of water sources [15], soils, and atmospheric air [16]. Statistics of *Fs* shows that the majority of them fall on objects of the residential, public, and industrial sectors [17]. The largest number of *Fs* (55 %) occurs in residential buildings. Maximum material damage is inflicted on industrial (45 %) and residential (35 %) objects. At the same time, the maximum number of dead people is typical for *Fs* in residential premises (80 %) [18]. Reducing the risk of *Fs* in premises can be implemented on the basis of preventive measures [19], early detection [20], and forecasting of *Fs* [21]. Preventive measures and forecasting of *Fs* [22] are usually aimed at reducing the overall risk of *Fs* in the future [23] and do not allow it to be reduced in the current time (CT). However, it is known that the harbinger of any *Fs* in the room is the accidental ignition (IG) of the material [24]. Therefore, in practice, the early detection of flammable materials is an urgent problem for improving the safety of objects.

2. Literature review and problem statement

In [25] it is noted that the detection of conditions for IG as early as possible and their suppression at the initial stages is an effective way to reduce the risk of *Fs* in CT. The study of fast and accurate detection of *Fs* based on the use of video technologies was carried out in [24, 26]. Compared to traditional technologies, such technologies have the advantages of quick response to information, visualization, intelligence, and easy integration with other systems. However, most *Fs* are often preceded by a long process of material smoldering without the appearance of a flame, forming a large amount of smoke and other dangerous parameters (DP) that reduce the reliability of *Fs* detection. At the same time, video technologies do not work under conditions of shadowing of *Fs*, as well as non-visible DP of the gas environment (GE). The general disadvantage of almost all detection algorithms based on video technologies is their complexity, dependence on many parameters, the requirement of significant computing resources, as well as limited resistance to perturbations of GE. The main difficulty of early DF in real premises is the complexity and individual nature (uncertainty, non-stationarity, and non-linearity) of the dynamics of DP (DOP) of GE in IG. In [27], the technology of the early DF is proposed under the conditions of uncertainty and non-stationarity of DOP of GE in premises. However, it is limited to the use of traditional first- and second-order statistics and is therefore of little use in the nonlinear case. In [28], the DF technology is studied based on the measurements of an arbitrary DP HS by the same type of sensors and the processing of measurements with the help of a neural network. However, this technology turns out to be difficult to implement, requires the setting of many parameters, and therefore turns out to be of little use for DF in CT. The technology of group processing of data from various types of sensors for fire alarm systems based on the principles of fuzzy logic is studied in [29]. At the same time, the technologies [28, 29] are difficult to implement, are limited to the use of traditional statistics, and are determined by a set of parameters. In addition, the technology is not sensitive to the nonlinearity of DOP of GE, which is necessary for DF in CT. The results of experimental research on the burning of plantation wood are presented in [30]. It has been established that such combustion is accompanied by uneven release of heat into the external environment. At the same time, the effect of wood burning on DOP of GE is not considered or studied. In [31], the dependence of the burning intensity of three types of wood on the power of an external heat source is investigated. At the same time, the experimental results are limited to the study of the dependence between the average power of the heat source and the average burning intensity. The influence of wood burning on DOP of GE is not studied in [31]. Analogous experimental studies for organic glass and cypress are performed in [32]. However, in [30–32], there are no results of the study of the selected distributed DOP of GE or their moments, which contain information about its nonlinear features. In particular, there are no studies of the dynamics of skewness and kurtosis (SK) of the distributed DOP of GE with wood in the premises. The DF technology based on the use of recurrent plots for DP GE is proposed in [33]. Despite the high potential of the DF technology, it remains quite complex and requires the determination of the recurrence region depending on the nature of the current non-linearity of DOP of GE. Under the conditions of uncertainty of DOP, it is not possible to fulfill the specified requirement. Therefore, in [34], the DF technology based on the adaptive adjustment of the recurrence region for the state vector of DP GE is considered. However, the technologies [33, 34], despite the noted advantages and possibilities of DF, turn out to be quite difficult to implement and have limited efficiency. In addition, there are no proposals for increasing the speed of technologies for the purpose of DF in CT, as well as their simplification, for example, based on the use of selective distributed DP GE or their SK coefficients, sensitive to the current nonlinearity of DOP GE at IG in the premises. The original technologies for identifying DP GE based on structure functions [35] and uncertainty [36] are recognized. The limitations of the technology [35, 36] should include the fact that they are based on statistics of no higher than the second order. Therefore, these technologies are not sensitive to the peculiarities of nonlinear DOP. In addition, the technology [35, 36] needs to determine the reliability of DP detection. At the same time, reliability estimates are known for sample distributions or moments of SK [37]. However, technologies based on sample distributions or SK are not considered in [35–37]. In [38], the peculiarities of the amplitude and phase spectra of DOP of GE at the intervals of the absence and presence of IG in the laboratory chamber are studied. It was established that the peculiarities of the dynamics are manifested in the region of higher frequency components of the phase spectrum. However, the intensity of the manifestation of these features tends to decrease with increasing frequency. Interesting from the point of view of the possibility of DF are the studies of the peculiarities of the amplitude spectra of the third order of DOP GE, presented in [39]. It has been experimentally confirmed that amplitude spectra of the third order (amplitude bispectrum (BS)) are sensitive to nonlinear features of DOP GE, which can be used for DF. However, the sensitivity significantly depends on the energy of a specific type of DP GE. Therefore, in [40] it is proposed to use phase BS or bicoherence (BC), which does not depend on the energy of DP and contains information about the peculiarities of the nonlinearity of DOP of GE. However, in [39, 40] studies are limited to selective amplitude and phase BS. At the same time, it is known that BS is usually calculated based on the averaging of sample BS over an ensemble of implementations [41, 42]. This means that additional studies of DF technologies based on the use of BS are necessary. At the same time, in [39–42] the studies are limited to the frequency domain. At the same time, the peculiarities of the non-linear DOP of GE in the time domain are not considered. Despite the wide possibilities of BS and BC, they will reveal the peculiarities of the non-linear DOP of GE, the DF technologies based on them require a preliminary transition from the time domain to the particular one. The correct transition in case of non-stationarity and uncertainty of DOP appears to be problematic.

There is a hell of a need to develop DF technologies on the basis of DOP GE when IG occurs in premises capable of performing temporary IG localization taking into account the uncertainty and nonlinearity of the current dynamics. However, in order to develop such technologies, it is first necessary to determine the measure of DOP under conditions of uncertainty and nonlinearity, as well as to study its dynamics in the absence and appearance of IG. Taking into account the uncertainty and nonlinearity of the dynamics, it is possible to use the SK coefficients of current sample distributed OPs of GE, characterizing their current features, as a measure. caused by nonlinear dynamics. In this regard, the study of the dynamics of the measure of SK distributed DP GE at the time of IG in the premises should be considered an unsolved part of the problem of DF at the current time.

3. The aim and objectives of the study

The purpose of this work is to reveal the peculiarities of dynamics in the skewness and kurtosis of dangerous parameters of the gas environment when materials ignite in the room. Differences in the dynamics of such a measure can be used to detect a fire in the current time for operational suppression of a fire and prevention of a fire in the premises.

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

– to justify the methodology for determining the dynamics of skewness and kurtosis of dangerous parameters of the gas environment at an arbitrary time interval of their observation;

– to conduct experiments to determine the dynamics of skewness and kurtosis of dangerous parameters of the gas environment in the laboratory chamber during the observation interval when the test materials ignite.

4. The study materials and methods

The object of our study was the dynamics of the measure of SK DP GE during the observation interval during the emergence of IG test materials (TM) in the laboratory chamber (LC). The working hypothesis assumed that the dynamics of measures of SK DP GE before and after the occurrence of IG TM have a different character. At the same time, it was assumed that the dynamics of measures of SK DP GE at the occurrence of IG in real premises and in LC are isomorphic [43]. Alcohol and textiles, which have different specific mass burning rates, were considered as TM [44]. It is known that the specific mass rate of combustion of TM determines the presence and properties of many OPs since the amount of combustion products largely depends on the amount and type of burned TM. Therefore, the temperature, smoke density, and CO concentration were considered as the main OS parameters. GE temperature was measured by a TPT-4 sensor (Ukraine) [45], smoke density by an IPD-3.2 sensor (Ukraine) [46], and CO concentration by a Discovery sensor (Switzerland) [47].

The main method of research was the selective method of determining the dynamics of measures of SK of real DOP of GE in LC with IG TM. At the same time, the sampling method was based on current measurements of DP in a moving fixed time interval. In accordance with the requirements of [48, 49], measurements of DP GE were made by sensors located in the ceiling area of LC. Measurements of DP GE by sensors were made discretely in time with an interval of 0.1 s. The total number of discrete measurements of each DP GE during the observation interval was 500 discrete readings. In order to reveal the differences in the dynamics of the measures of SK DP GE at IG of the materials, a moving time interval of a fixed duration, determined by 20 discrete readings, was selected. This interval was successively moved along the observed observation interval as discrete DP values were obtained. At the same time, approximately 240 samples were produced from each of TMs. The results of current discrete measurements of DP GE were stored in the computer memory for their subsequent processing in order to determine measures of SK DP GE in CT. After each of the specified materials, natural ventilation of the chamber was carried out through the available opening of the chamber for 5–7 minutes. Such ventilation was intended to restore the initial state of DP GE after IG of TM. The processing of discrete measurements of DP was carried out on the basis of the method of non-parametric estimation of sampling moments of distribution [50].

5. Results of research into the dynamics of skewness and kurtosis

5. 1. Justification of a methodology for determining the dynamics of the skewness and kurtosis of dangerous parameters of gas environment during fires

Let the measurements of an arbitrary DP GE on the observation interval $[0, T]$ in continuous time be described by the realization $x(t)$, $t\epsilon[0, T]$. This implementation in discrete time will correspond to a sample $(x_0, x_1, x_2, ..., x_n)$ of fixed size n. In this case, the value of n is determined by the value of the end of the observation interval. In the CT measurement of DP, the sample $(x_0, x_1, x_2, ..., x_n)$ is known only up to and including some current p-th discrete measurement. Therefore, the sample $(x_0, x_1, x_2, ..., x_n)$ is a sample $(x_0, x_1, x_2, ..., x_p)$ of increasing size $0 \leq p \leq n$. It is known that the complete characteristic of a sample of any size is its sample distribution [51]. However, in practice, it is inconvenient to use the sampling distribution since it is a visual representation of the statistical features of the sample [52]. Therefore, they usually use various numerical characteristics of the distributed in the form of their moments, which approximately describe the statistics of distribution [53]. Following [38–40], the distributions of DP GE at IG are recognized as non-Gaussian and belong to the nonparametric family W. In this case, distributions of DP GE are usually not known a priori and change over time. In this case, sampling points can be used for sampling [54]. The first and second central moments characterize the mean and variance of the unknown distributed sample. However, these moments fully characterize samples only if their distributions are Gaussian. SK coefficients are usually used for non-Gaussian distributions. To determine the dynamics of the SK measure of DP, we will consider a special interval of discrete measurements, on the basis of which the corresponding SK measures will be calculated. Let the beginning of such a special interval be determined by an arbitrary index $n0$, and the end of the special interval by nK. At the same time, the nK index coincides with the p index characterizing the current measurement time. By moving a special interval in time, it is possible to determine the dynamics of the mathematical expectation Mx_p and dispersion Dx_p of an arbitrary DP GE in CT, using the following relations:

$$Mx_p=\mathrm{if}\left[p\le nK,\sum_{i=n0}^{p}\frac{x_{p-i}}{p-n0+1},\sum_{i=n0}^{nK}\frac{x_{p-i}}{nK-n0+1}\right],$$

$$Dx_p=\mathrm{if}\left[\begin{matrix}p\le nK,\sum\limits_{i=n0}^{p}\dfrac{\left(x_{p-i}-Mx_p\right)^2}{p-n0+1},\\ \sum\limits_{i=n0}^{nK}\dfrac{\left(x_{p-i}-Mx_p\right)^2}{nK-n0+1}\end{matrix}\right]. \qquad (1)$$

Taking into account (1), the dynamics of the selective central moments of the third $M3x_p$ and fourth $M4x_p$ order will be determined, respectively, by the relations:

$$M3x_p=\mathrm{if}\left[\begin{matrix}p\le nK,\sum\limits_{i=n0}^{p}\dfrac{\left(x_{p-i}-Mx_p\right)^3}{p-n0+1},\\ \sum\limits_{i=n0}^{nK}\dfrac{\left(x_{p-i}-Mx_p\right)^3}{nK-n0+1}\end{matrix}\right],$$

$$M4x_p=\mathrm{if}\left[\begin{matrix}p\le nK,\sum\limits_{i=n0}^{p}\dfrac{\left(x_{p-i}-Mx_p\right)^4}{p-n0+1},\\ \sum\limits_{i=n0}^{nK}\dfrac{\left(x_{p-i}-Mx_p\right)^4}{nK-n0+1}\end{matrix}\right]. \qquad (2)$$

On the basis of (1), (2), the dynamics of skewness ASx_p and kurtosis ESx_p of an arbitrary DP GE x_p at a discrete moment p can be determined:

$$ASx_p=\frac{M3x_p}{\left(Dx_p\right)^{3/2}},\quad ESx_p=\frac{M4x_p}{\left(Dx_p\right)^2}-3. \qquad (3)$$

It should be noted that sample moments (1), (2) with significant sample sizes are unbiased and effective estimates of the corresponding distributed moments, and under the condition $nK\to\infty$ they are also consistent and asymptotically Gaussian. SK measures (3) for the sample $(x_0, x_1, x_2, ..., x_p)$ from the family of Gaussian distributions will be close to zero values. In the case of sampling $(x_0, x_1, x_2, ..., x_p)$ from the family of non-Gaussian distributed measures (3) will have values different from zero. The advantage of measures (3) should be considered that they are considered current. At the same time, the accuracy of the specified measures is characterized by the corresponding variance [55]:

$$D\left(ASx_p\right)=\frac{6\left(K2-1\right)}{\left[\left(K2+1\right)\left(K2+3\right)\right]},$$

$$D\left(ES_p\right)=\frac{24n1\left(n1-2\right)\left(n1-3\right)}{\left[\left(n1+1\right)^2\left(n1+3\right)\left(n1+5\right)\right]}, \qquad (4)$$

where $K2=nK-n0$ is the size of the sample by which measures are determined (3). It follows from expression (4) that the accuracy of measure (3) is determined only by the sample size $n1$. However, the choice of the sample size will have different effects on the possibility of detecting IG in CT based on the dynamics of measures (3). Thus, from the point of view of temporal localization, the sample size should be minimal. However, the accuracy of current measures will decrease (3). This means that the detection of IG based on the dynamics of measure (3) requires a compromise when choosing the sample size $K2$. Finding IG, based on the dynamics of measures (3), is connected with the adoption of appropriate decisions. Any decision is based on hypothesis testing. The first null hypothesis H_A is that the first current measure (3) is zero. The second null hypothesis H_E is the second current measure (3) equal to zero. Then the alternative hypotheses will be, respectively, that the current measures (3) are different from zero. Usually, the level of significance is understood as the probability of falsely rejecting the null hypothesis. At the same time, each level of significance corresponds to its own level of confidence, determined by the value that complements the given level of significance to unity. Let the decisions in favor of hypotheses H_A and H_E be characterized by significance levels α_A and α_E, respectively. Usually, it is customary to use significance levels of 0.01, 0.05, and 0.1. Then, following the generalized Chebyshev inequality taking into account expression (3), we obtain the expressions that determine the threshold values $Aa(K2, \alpha_A)$ and $Ea(K2, \alpha_E)$ for SK measures, respectively, depending on the sample size $K2$ and the specified significance levels α_A and α_E:

$$Aa\left(K2,\alpha_A\right)=\pm\sqrt{D\left(ASx_p\right)/\alpha_A},$$

$$Ea\left(K2,\alpha_E\right)=\pm\sqrt{D\left(ESx_p\right)/\alpha_E}. \qquad (5)$$

Based on (5), it is possible to determine the conditions under which decisions in favor of the corresponding null hypotheses for the current values of SK measures are significant. Such conditions can be represented in the form of inequalities:

$$\left|ASx_p\right|<\left|Aa\left(K2,\alpha_A\right)\right|,\quad \left|ESx_p\right|<\left|Ea\left(K2,\alpha_E\right)\right|. \qquad (6)$$

If conditions (6) are met for measures (3), then it is assumed that the values of the corresponding measure are significant, and a decision is made in favor of the null hypothesis for this measure at a given significance level. Otherwise, the corresponding null hypothesis is rejected.

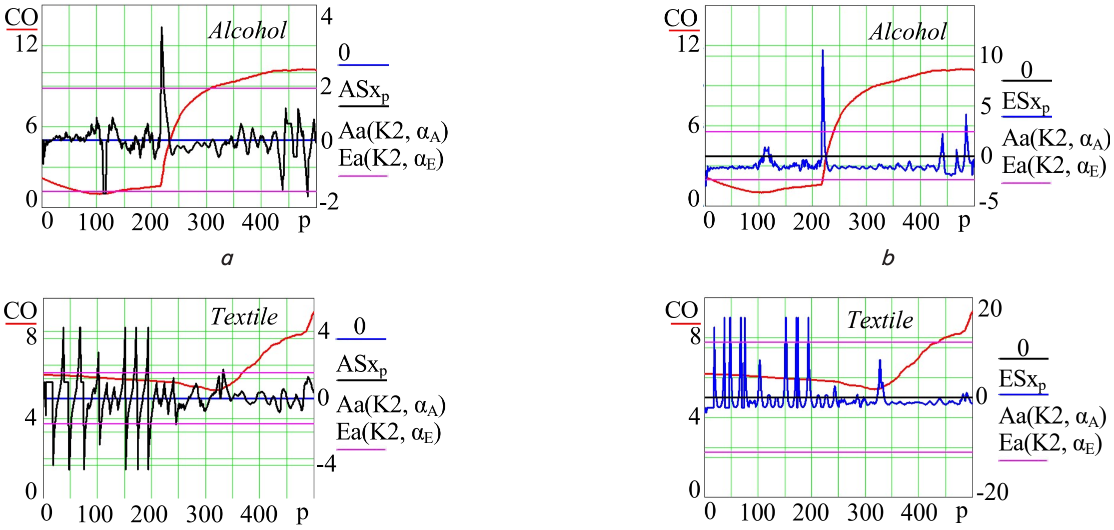
Thus, measures (3) make it possible to identify the features of the dynamics of SK sample distributions for an arbitrary DP GE in CT observation. In this case, expressions (5) determine the corresponding threshold values of SK measures at which they are significant. This makes it possible, with a given level of significance, to identify current moments in time of significant SK of sample distributions of GE DP. In the case of small values of SK measures, it can be assumed that the DP distributions are characterized by weak symmetry and the absence of significant deviations from the average. However, it is not possible to assert that the distribution is Gaussian. At the same time, significant SK measures will indicate that the DP distributions are characterized by significant asymmetry and the presence of significant deviations relative to the average. Therefore, this procedure allows us to identify the features of sample distributions of GE OPs, characterized by their SK for an arbitrary sample size in CT. This suggests the possibility of early detection of IG of materials based on changes in sample distributions of GE DP in CT, characterized by SK dynamics.

5. 2. Results of experiments to determine the dynamics of skewness and kurtosis of gaseous medium parameters in a laboratory chamber

As a result of our experiment, the dynamics of the SK measure of the DP GE at IG of two TMs, characterized by significantly different specific mass burnup rates, was determined. The study of the dynamics of the SK measure of DP GE was carried out with a fixed sample size $K2=20$ and significance levels $\alpha_A=\alpha_E=0.1$. This significance value corresponds to 90 % confidence in the decision in favor of the corresponding null hypotheses. Fig. 1 shows the experimental dynamics of the skewness (black curve) and kurtosis (blue curve) for the concentration of CO GE in LC at IG of alcohol and textiles.

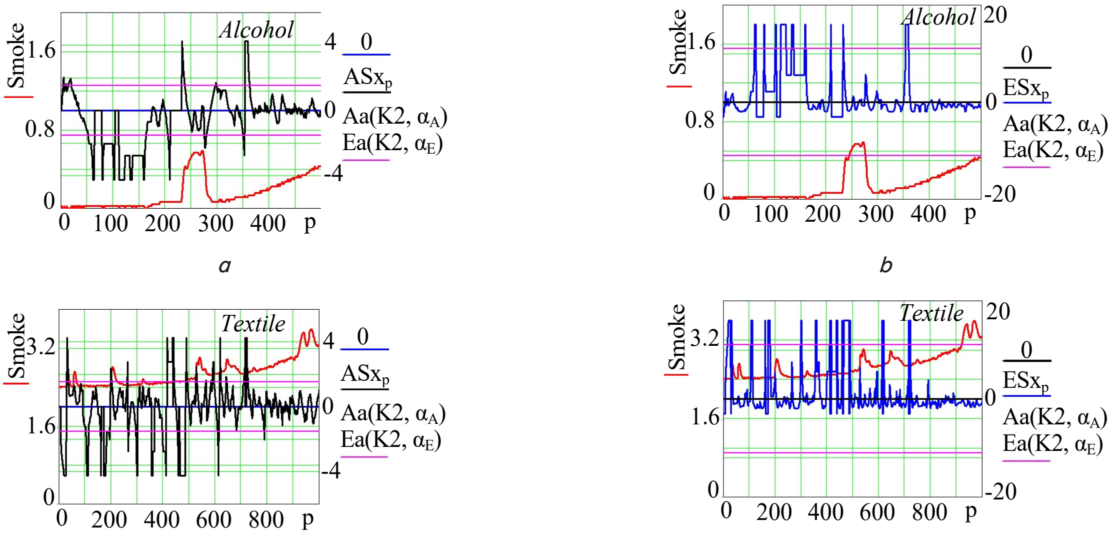
Similar dependences for smoke density and temperature are shown in Fig. 2, 3.

In Fig. 1–3, the dynamics of the corresponding DP GE are illustrated by red curves. Lilac color shows threshold values $Aa(K2, \alpha_A)$ and $Ea(K2, \alpha_E)$ for a given sample size and significance levels.



a *b* *c* *d*

Fig. 1. Experimental dynamics of the skewness and kurtosis of CO concentration during ignition of test materials: *a* – skewness for alcohol; *b* – kurtosis for alcohol; *c* – skewness for textiles; *d* – kurtosis for textiles



a *b* *c* *d*

Fig. 2. Experimental dynamics of the skewness and kurtosis of smoke density during ignition of test materials: *a* – skewness for alcohol; *b* – kurtosis for alcohol; *c* – skewness for textiles; *d* – kurtosis for textiles

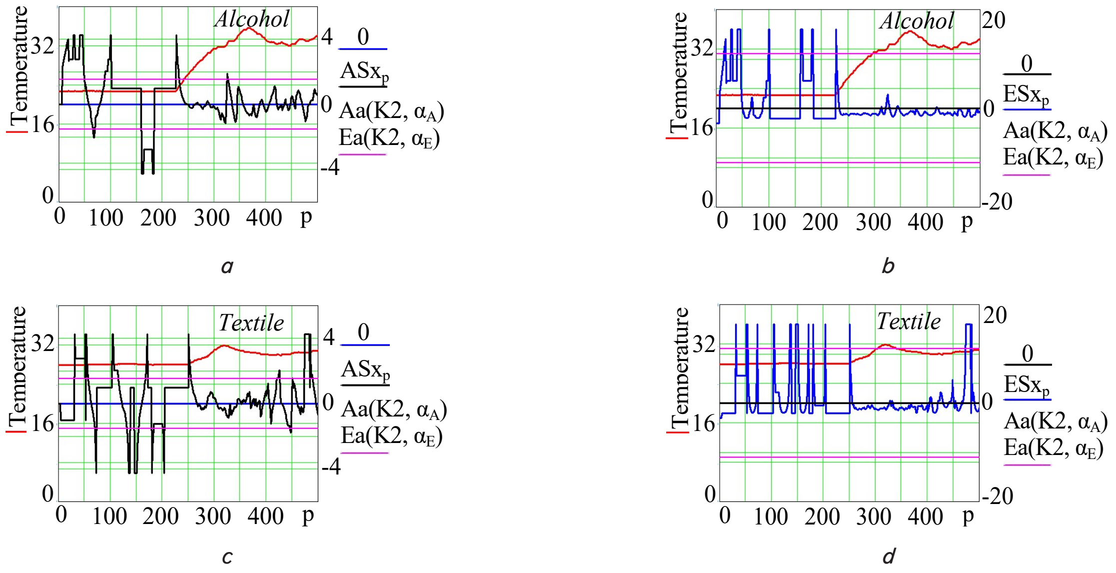


Fig. 3. Experimental dynamics of measures of asymmetry and temperature kurtosis during ignition of test materials: *a* — skewness for alcohol; *b* — kurtosis for alcohol; *c* — skewness for textiles; *d* — kurtosis for textiles

6. Discussion of results of investigating the dynamics of skewness and kurtosis

Skewness usually characterizes the asymmetry of the frequencies of occurrence of data in the sample that are higher and lower than the average value. In this case, the sign and magnitude of the measure characterize the degree (frequency) and side of the asymmetry of the GP DP values. Zero values of skewness indicate that sample values of the parameter, both above the average and below the average, occur equally frequently. The kurtosis measure characterizes the frequency of occurrence of large data values in the sample compared to a Gaussian sample, and its sign indicates the side of these deviations relative to the average. From the analysis of Fig. 1–3 it follows that the dynamics of the SK measure of the considered DP GE at alcohol and textiles IG turns out to be heterogeneous over the observation interval. This is explained by various complex mechanisms for the formation of the current values of such DP GE in the absence and appearance of TM IG. At the same time, the dynamics of the SK measure generally indicates the nonlinearity of the processes describing changes in the DP of GE over the observation interval. This result does not contradict modern ideas about the nonlinearity of changes in GE parameters during TM IG. However, the curves in Fig. 1, *a*, *b* show that for the concentration of CO GE before the moment of alcohol IG and after it, the dynamics of the SK measure are of a fluctuating nature within the given boundaries. In this case, the fluctuating nature of the dynamics of the kurtosis measure is characterized by a small negative average value. At the moment of alcohol IG, the SK measures increase significantly and take values above 3 and 10, respectively, which significantly exceed the permissible positive limits of significance. The fluctuating nature of the dynamics of skewness is usually considered as an indicator of sustainability (unsustainability) of development and one of the indicators of environmental quality [56, 57]. By analogy, the fluctuating nature of dynamics of the skewness of the concentration of CO can also be interpreted as a certain indicator of the stability of the process of formation of the concentration of CO GE. In this case, a sharp increase in the skewness of the CO concentration above the permissible limit at the moment of alcohol IG should be interpreted as a reaction of the indicated parameter GE LC to IG. In this case, such a reaction means a short-term increase in the stability of the CO concentration. Curves in Fig. 1, *c*, *d* show that when textiles are ignited, the nature of dynamics of the skewness of CO concentration is also fluctuating. However, in the absence of IG, the nature of dynamics of skewness differs from the case in the absence of alcohol IG. This is explained by the different nature of change in CO concentration due to the different initial state of GE in the chamber. In this case, the dynamics of the skewness are quasi-periodic in nature with short-term alternating directional asymmetry of more than 4 units. This means that until the moment of textile IG, the CO concentration is characterized by dynamic stability. In this case, the protection of textiles leads to a violation of dynamic stability, accompanied by the appearance of fluctuating asymmetry. Dynamics of the kurtosis measure in Fig. 1, *c*, *d* in this case clarify that in the absence of IG, dynamic stability is characterized by the predominance of quasiperiodic large positive values of CO concentration. In the case of textiles, a violation of stability is accompanied by slight fluctuations in the negative values of kurtosis.

The dynamics of the smoke density skewness in the absence of alcohol IG (Fig. 2) is random and ensures the dynamic stability of the smoke density due to the predominance of negative values exceeding 4 units. With alcohol IG, the dynamic stability of the smoke density is disrupted, which leads to fluctuating asymmetry. Analysis of the dynamics of the kurtosis in this case indicates that the dynamic stability of the smoke density is accompanied by values of the kurtosis exceeding 10 units. At alcohol IG, the loss of smoke density stability is characterized by the fluctuating dynamics of kurtosis. For textiles, in the absence and presence of IG, the dynamics of the skewness for smoke density are characterized by a random alternation of short-term stable and unstable states over an observation interval of 500 counts. Short-term stability is ensured by positive and negative values of the measure of directional asymmetry exceeding 1.536 units, and short-term instability is ensured by values of the module of the skewness less than 1.536 units. From the curves in Fig. 2, *c* it follows that the dynamics of the measure of smoke density asymmetry over an observation interval of 500 counts turn out to be uninformative from the point of view of operational textile inspection. This is explained by the low specific mass burnout rate of textiles compared to alcohol. Similar conclusions are valid for the dynamics of kurtosis (Fig. 2, *d*). In this case, short-term stability is determined by the current kurtosis exceeding a value equal to 11.029 units. The dynamics of the kurtosis of smoke density over an observation interval of 500 counts also turn out to be uninformative from the point of view of operational textile inspection. If we take into account the low specific mass rate of textile burnout and increase the interval to 1000 counts, then the dynamics of SK measures for smoke density indicates a loss of stability in the formation of smoke density with a time delay. Therefore, for operational air pollution it is not possible to use the dynamics of SK measures for smoke density. In this case, the dynamics of the skewness of the temperature of GE in the absence of alcohol IG is characterized by random intervals of different durations, during which the values of the measure are more or less than the significance thresholds (Fig. 3, *a*). This means the dynamic stability of the temperature of GE in LC before the alcohol IG. In the case of alcohol IG, the GE temperature loses its dynamic stability, and the dynamics of the skewness take on a fluctuating character. A similar loss of stability of GE temperature is confirmed by the dynamics of kurtosis (Fig. 3, *b*). The dynamics of the temperature skewness in the absence of textiles are characterized by random intervals of varying duration, during which the measure values exceed or fall below the significance thresholds (Fig. 3, *c*). This indicates the dynamic stability of GE temperature in the absence of textile IG. At textile IG, the dynamics of the skewness for the GE temperature have a fluctuating character, indicating temperature instability (Fig. 3, *d*).

Our results indicate the possibility of operational monitoring based on the dynamics of SK measures for CO concentration and GE temperature. Using the dynamics of SK measures of smoke density for IG of materials with a low specific mass burnout rate is possible but it is necessary to take into account the corresponding time delay of DF. This technique makes it possible to determine the dynamics of SK measure for an arbitrary sample size of any DP GE in CT. The scientific novelty is the methodology for determining the dynamics of SK measures for DP GE, introducing null hypotheses and calculating the threshold for their acceptance, taking into account the level of significance and sample size, as well as the features of the experimental dynamics of SK measures of DP GE in LC at IG of alcohol and textiles. In practice, this will make it possible to increase the efficiency of protecting premises from fires due to DF in CT and their prompt suppression to prevent fires.

Limitations of the study include the consideration of CO concentration, smoke density and temperature as DP GE, as well as the use of LC and two types of materials in the form of alcohol and textiles. The development of the research is expected in the directions of overcoming the noted limitations.

7. Conclusions

1. A theoretical substantiation of the methodology for determining the dynamics of the skewness and kurtosis has been carried out based on a sample of an arbitrary size of dangerous parameters of the gaseous medium moving in the current observation time. Thresholds for current measures of skewness and kurtosis are determined depending on the sample size and significance levels of the corresponding null hypotheses (instability in the dynamics of a dangerous parameter). The procedure makes it possible to study the features of dynamics in the skewness and kurtosis for an arbitrary sample size of any dangerous parameter of the gaseous environment in real time, and also, taking into account a given level of significance, to identify current moments in time when alternative hypotheses are valid.

2. Laboratory experiments were carried out to study the peculiarities of dynamics of the skewness and kurtosis of CO concentration, smoke density, and gas temperature when alcohol and textiles ignite in the chamber. The results indicate that the studied hazardous parameters of the gas environment over the observation interval are characterized by non-Gaussian sample distributions. Features of dynamics of the skewness and kurtosis for current sample distributions of dangerous parameters of the gaseous environment depend on the material of the fire and the dangerous parameter being studied. It has been established that in the absence of fires, the dynamics of the skewness and kurtosis are characterized by varying degrees of directional asymmetry and kurtosis, which generally indicate the stability of the development of a dangerous parameter over time. When fires occur, the dynamics of the skewness and kurtosis have a fluctuating character (from –4 to 18), which indicates a violation of stability and a transition to an unstable change in the observed dangerous parameter over time. At the same time, the described procedure makes it possible to identify instability in the development of a dangerous parameter caused by the combustion of a material with a given reliability.

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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