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LEVEL OF FIRE DANGER OF THE LOCAL TERRITORY

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The object of the study is the fire risk of the local area. The problem to be solved is to take into account most of the significant parameters in the territorial placement of fire-rescue units of different functional capacities. As part of the solution to this problem, a technique for assessing the fire risk of a large-scale local area has been developed. The methodology is focused on local territories of a large area with a low population density. A special feature of the proposed method is the differentiated fire risk assessment of each point of the surface plane. For such an assessment, the parameters that are decisive from the point of view of impact on the fire hazard are analyzed and structured. The specified factors include the spatial distribution of population density and buildings, the transport and communication network, the spatial distribution of the density and type of vegetation, and statistical data on landscape fires. The use of existing geo-informational resources in real time is foreseen. A new approach of ranking the fire risk of the elementary plane of the territory in accordance with the necessary number of resources of rescue units to ensure the appropriate level of safety is proposed. Neural network data processing methods were used to compare local area parameters with fire risk ranks. A neural network capable of comparing the fire risk of the territory with its parameters was obtained. The functionality of the developed methodology was tested and the fire risk levels of an arbitrary area were graded with an average degree of correlation of 0.97. The proposed method allows for assessment and correction of the state of provision of local territories with civil protection resources. The developed methodology is especially relevant when creating new fire and rescue units of territorial communities

Keywords: fire risk, local territory, fire station, service area, neural network, population density

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1. Introduction

The development of humankindpredetermines an increase in the level of threats of both man-made [1, 2] and natural nature [3]. The most intense are dangerous events associated with local fires (LF) [4]. LF cause death and injury to people [5], lead to the destruction and damage of industrial [6] and residential facilities [7, 8]. Of particular danger are LF in ecosystems [9]. Combustion products and extinguishing agents [10] cause pollution of water sources [11], soils and atmospheric air [12], which globally provokes acid precipitation and increased greenhouse effect [13]. CounteractingLF is based on two directions. Prevention involves preventive measures [14] and detection of fires in the early stages [15]. Extinguishing implies timely response to LF with a sufficient amount of resources [16]. It is important to optimize the cost of ensuring fire safety (FS). At the same time, optimization is between two factors – material costs that strive to a minimum, and the level of FS, which tends to the maximum but should not be lower than the established norms. Based on this, the optimal way to ensure FS will be the compliance of all fire-fighting measures within the local territory (LT) with the level of FS of this territory.In addition to the large number of factors affecting the FS of a region, its assessment significantly complicates the uneven distribution of such factors throughout the territory. Based on the fact that for fire and rescue units (FRU) the time of arrival at the place of call plays a critical role, their number within the settlement and territorial location is very important. Exceeding the time of FRU traveling to the place of LF leads to an increase in human and material losses, as well as excessive release of combustion products [17, 18]. The main reasons for exceeding the normalized time of arrival of FRU are exceeding the normalized distances [19] to dangerous objects [20], incorrect choice of routes, and inconsistency in the state of the transport network [21]. In addition to a large number of significant parameters, the issue of territorial location of FRU is complicated by the constant change of such parameters. Therefore, the question of the number and location of FRU needs constant clarification. Thus, the imperfection of existing methods and approaches to taking into account significant parameters in the territorial placement of FRU of different functional capacity is an urgent problem.

2. Literature review and problem statement

Analysis of the state of fire danger (FD) in different countries as a whole and in individual regions is carried out within the national structures for monitoring the state of technogenic and natural safety [22]. The annual reports provide statistics of LF by their nature, the number of dead, injured, and material damage. Using these data, an analysis of fire risks (FR) of individual regions is carried out [23]. However, in this case, FR is determined by the ratio of the number of LF per LT to the number of the population, the number of dead, the number of injured, and material damage, which makes it impossible to estimate FR in areas with a low frequency of fires.A separate factor is the negative impact of large-scale LF on the air ecosystem [24]. The advantage of this method is the ease of calculation and a small amount of necessary input data, which correlates with annual statistics. There are fairly accurate methods for predicting FD, which are based on the processing of a large number of statistical data [25]. But at the same time, this method has significant drawbacks – it is the failure to take into account a number of significant factors, complete dependence on statistical data, and focus on the territory of a large area for which it is possible to collect such an array of data. To realize the possibility of assessing the level of FD on LT of arbitrary size, the calculation of FR is provided as an integrating indicator for a number of hazard factors, which are given a certain rank [26]. The FR criteria include the scope of operation of objects, their area and height, the number of people who can simultaneously be at the facilities, the presence and scale of LF in recent years. But the list of these criteria is insufficient and does not make it possible to fully assess the level of FD of an object or territory. Therefore, ISO 16732-1:2018 proposes a method for calculating the total FR, as an integrating indicator of individual, social, and potential FR. However, this technique defines FR as the probability of an incident. This approach does not make it possible to correlate the level of FD LT and the necessary measures to ensure FS. When analyzing FR on a large-scale LT, additional hazards, such as the type and density of vegetation, terrain, and the presence of water sources, become important [27]. A more complete description of FR is provided by the international standard ISO 31000:2018, where FR is an integrating indicator for assessing the sources of danger, possible consequences, and their probability. But there is no method for numerical evaluation of such parameters for large-scale LT, and the calculation requires a significant array of engineering, social, and statistical data. The level of FR is also affected by the presence and condition of fire protection systems, such as early detection, warning and automated extinguishing systems of LF [28]. However, no general approach has been created to assess the degree of influence of such systems on the level of FR as a separate object and LT as a whole.When choosing a place to place a new FRU or assess the correctness of the placement of already created FRU, it is necessary to take into account the number of fire hazardous objects, the degree of their FD, territorial location, the presence and condition of access roads [29]. In its simplest form, the issue of placing FRU is solved as a problem of placing circles of a certain radius. In this case, the determining parameter is the time of arrival of the unit at the place of LF [30]. The limiting radius of the circle is determined on a condition that this time should not exceed the established values, taking into account the speed of movement of the fire truck. However, the work does not take into account the state of transport communications. Determination of the limits of maintenance of FRU, taking into account the presence and condition of highways, was carried out in [31], where the service area of FRU has the form of a polygon. However, the different level of FD of objects and the different functional capacity of FRU are not taken into account. Automation of the process of placing FRU on the map of a district or city using the GIS program was carried out in [32]. The proposed algorithm allows interactive use of digital maps with additional application of layers with the transport network and FRU [33]. However, when extinguishing complex LF, it is necessary to involve several FRUs, which do not make it possible to make results in [33]. Assessment of the level of FD of the district takes into account many parameters and is carried out by separate methods for the city and forest [34]. Nevertheless, such methods are quite abstract. The method of spatial calibration of territories according to the stages of FR [35] has been widely used. At the same time, this method is well suited only to LT of the same fire load, for example, forests, fields, etc. Taking into account FR in dense diverse buildings requires consideration of the characteristics of each individual object. Thus, the unresolved part of the problem under consideration is the lack of methods and approaches to assessing the level of FDover LT of a large scale with the definition of the necessary fire-fighting forces and means.

3. The aim and objectives of the study

The aim of our work is to develop a methodology for assessing the level of fire danger of a large-scale area with the definition of the necessary fire-fighting forces and means. This technique will make it possible to assess and adjust the state of provision of local territories with civil protection resources.

To accomplish the aim, two tasks have been set:

– to theoretically substantiate the methodology for assessing the level of fire danger of a local area of a large scale by structuring the determining parameters of fire danger, using artificial intelligence methods and GIS technologies;

– to check the operability of the methodology for assessing the level of fire danger of a local area of a large scale.

4. The study materials and methods

The object of this study is FRover LT of a large scale. The working hypothesis assumed the difference between the FR of the elementary plane of the territory, depending on the characteristic parameters. The identified differences in the assessment of FR of each surface point will determine the required amount of civil protection resources to ensure the proper level of large-scale FSof LT. The methods of system analysis, statistical data processing, as well as methods of artificial intelligence and GIS technology were used in the work. The implementation of artificial intelligence methods was carried out using the STATISTICA 10 software package (USA). To analyze the spatial distribution of population density, type, and density of vegetation and fire activity over LT, data from the resources of the Fire Information for Resource Management System (FIRMS) [36] and Global Fire Atlas [37] were used.

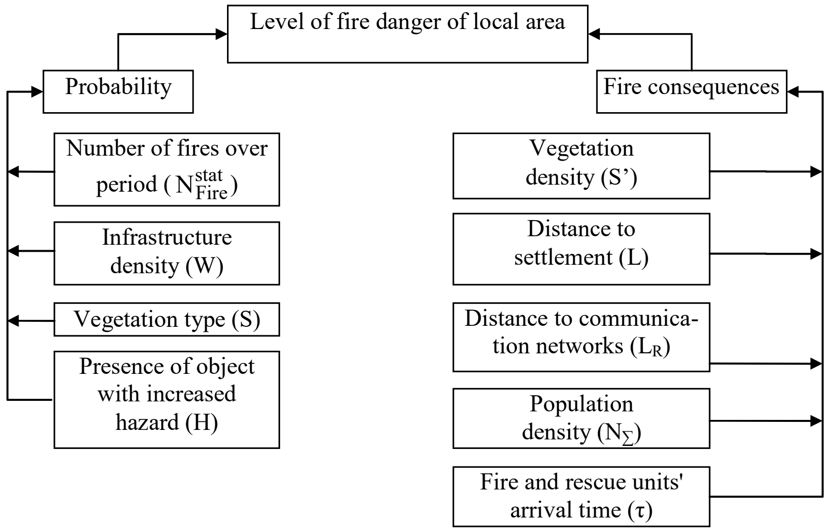

Fig. 1. Integrated structure of factors for comprehensive assessment of the level of fire danger of a local area of a large scale

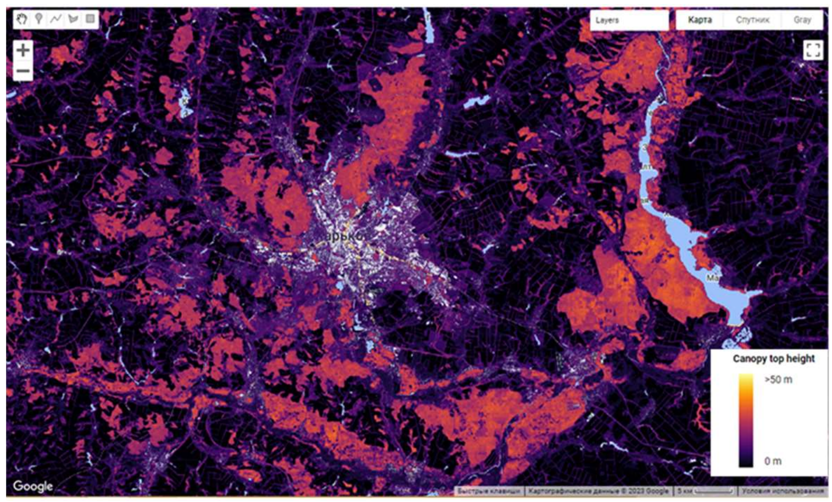

Fig. 2. Vegetation density map of a large-scale local area according to the GEDI and Sentinel-2 satellites

5. Results of the development of a methodology for assessing the level of fire danger of a large-scale area

5. 1. Theoretical substantiation of the methodology for assessing the level of fire danger of a large-scale area

The level of FD by analogy with risk is determined by the probability of the onset of LF and the corresponding consequences [38, 39]. To be able to assess the level of FD, the determining factors for densely built areas and sparsely populated areas were analyzed and structured [40–42]. The complex structure of factors for the integrated assessment of the level of FD LT of a large scale is shown in Fig. 1.

According to the complex structure (Fig. 1), the following factors influence the probability:

1. The density of the plant cover determines the intensity of LF and the rate of LF propagation over the surface of LT. The best reflection of the density of vegetation cover is provided by the mapping resource Awesome Gee Community Catalog [43]. This resource providesinformation based on the integration of data from satellite systems GEDI, Sentinel-2 (Fig. 2).

The GEDI satellite system provides resolved altitude data with unprecedented coverage. Optical satellite images such as Sentinel-2 offer dense observations around the world but cannot directly measure vertical structures. Combining GEDI with Sentinel-2, a probabilistic deep learning model for cover height with a quantitative assessment of uncertainty was developed [44].

2. The distance to the settlement has a complex impact on the risk. The main component is the time before the detection of LF and the time of arrival at the place of LFby FRU. Detection times can vary in a very wide range from a few seconds at facilities equipped with automatic alarms up to several hours in the case of landscape LF in the depths of the forest. The same trend applies to the time of arrival. While for densely populated cities the arrival time of FRU is 5–10 minutes, for forest LF in general there is a significant difficulty in delivering LF extinguishing agents to the cell. But the distance to the settlement indirectly affects the likelihood of F. This is explained by the fact that the cause of most landscape LF is the human factor. That is, the distance from the settlement reduces the likelihood of F.

3. The distance from the communication routes directly affects the time of arrival of FRU to the F site. The esti-

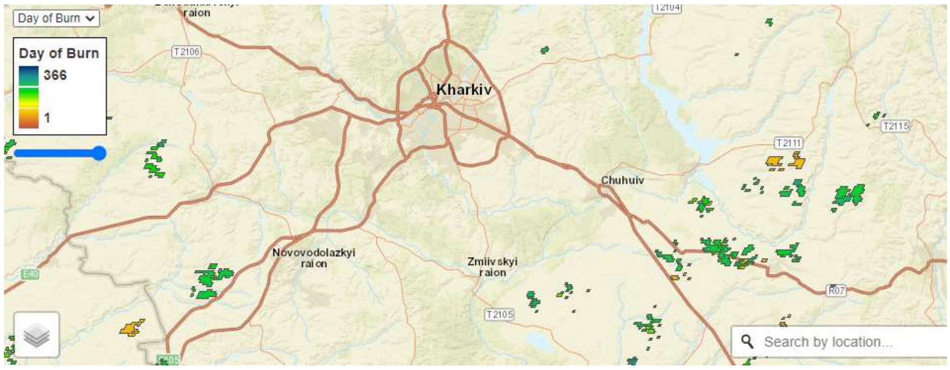

Fig. 3. Duration of landscape fires in the local area in 2022 according to Global Fire Atlas [35]

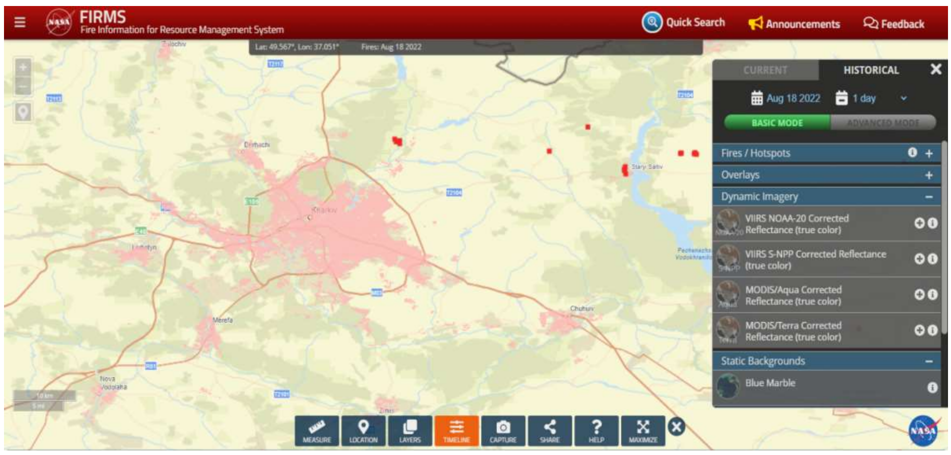

Fig. 4. Spatial distribution of building density in the FIRMS resource

mated speed of a fire truck on an asphalt road is 60 km/h; on unpaved roads – 20 km/h and below.

4. The population density determines the number of people who can get into F site. Accordingly, this indicator will directly proportionally determine the number of dead and injured because of F.

The possible consequences of probable LF are determined by the following factors:

1. The number of LF for a certain period or their duration can be obtained from statistical references. Data collection on landscape LF in steppes and forests is carried out by the Moderate Resolution Imaging Spectroradiometer (MODIS) system. MODIS is a key tool for the Terra and Aqua satellites. These satellites monitor the entire surface of the Earth every 1–2 days, obtaining data in 36 spectral ranges. Such data can improve the analysis of global dynamics and processes occurring on land, in the oceans, and the lower layers of the atmosphere.The results of the analysis of satellite information by the Global Fire Atlas service are shown in Fig. 3. The map (Fig. 3) shows the places of abnormal temperature activity, indicating the occurrence of LF and the duration of such LF by day of the year. The FD of such LF is due not only to the combustion factor but also to a significant environmental threat due to the release of hazardous gases into the atmosphere [45]. To reduce this effect, separate methods are being developed [46].

2. On LTof individual administrative regions, there is a significant uneven density of the population. Within such districts there may be large cities, cities with a population of less than 100 thousand people, and settlements – up to 10 thousand persons. To form the area of departure of FRU, it is necessary to know the spatial distribution of population density. An example of a public database with such information is the FIRMS service (Fig. 4), which contains information on the spatial location of the building in the form of an additional layer of Human Built-up and Settlement Extend.

3. The type of vegetation has a complex effect on several FD factors at once. Firstly, it is the minimum energy of the ignition source, which is sufficient for the occurrence of F. This factor determines the likelihood of LF based on comparison with nearby sources of inflammation. In addition, the type of vegetation determines the rate of spread of LF over the surface of LT. There are two fundamentally different classes of vegetation – steppe and forest.

4. The presence of objects of increased FD determines the concentration of high-energy ignition sources. At industrial facilities, such sources of ignition as a high voltage current arc, friction sparks, an open flame, violation of occupational safety rules and FS are usually present in the aggregate.

However, it is not possible to generate a classic model of FD level from the factors outlined above. This is due to the diversity and uncertainty of the impact of such parameters on the level of FD LT of a large scale. Taking into account the above-mentioned, an approach is proposed to rank the level of FD LT of a large scale, which is based on the need for equipment with personnel to extinguish F. Results of such a ranking are given in Table 1.

Table 1

Ranking of a local area of a large scale according to the level of fire danger, depending on the required number of vehicles with personnel to extinguish fires

Rank, R_{LT}	Required number of vehicles with personnel
I	1
II	2
III	4
IV	6
V	10
VI	15
VII	21
VIII	28
IX	40
X	>40

Further, it is proposed to use an artificial neural network to analyze parameters that affect the level of FD LT of a large scale. The peculiarity of this technology is the possibility of processing large arrays of experimental and statistical data of any complexity in the absence of a priori information on the relationships between them. This became possible due to the ability ofthe network to self-learn when searching for the relationship between input and output parameters.The use of graphic data shown in Fig. 2–4 allows for a pixel-to-pixel analysis of the selected area of large-scale LT. As a result of training a multilayer perceptronic neural network, 4 best predictive models with MLF 12-9-3-1, MLF 12-7-1, MLF 15-5-1, MLF 15-2-1 architecture were obtained. The influence of the main parameters of large-scale LT on the level of FDare given in Table 2.

can be significantly improved by increasing the number of statistically processed points of a different nature on an arbitrary LT. Since the MLF 15-5-1 neural network has the ability to self-learn, adding new statistics will adjust the predictive model in the direction of clarifying the assessment. Graphic representation of the results is shown in Fig. 5.

Based on the fact that the dimensions of a single pixel are small relative to the distance to FRU, when solving the problems of placing FRU, each pixel can be considered as an elementary point, and its dimensions can be neglected. Cartographic calibration of the territory according to the levels of FD allows for its zoning and determination of the sufficiency of the provision of forces and means. The use of the proposed approach will make it possible to assess the level of FDover LT of arbitrary scale within the city, district, region, state.

Table 2

Characteristics of prognostic models for neural network assessment of the level of fire danger of the local territory

Model architecture	MLF 12-9-3-1	MLF 12-7-1	MLF 15-5-1	MLF 15-2-1
Learning productivity	0.892	0.842	0.827	0.816
Test error	148.5	112.8	76.4	85.9
Learning algorithm	BFGS 2	BFGS 4	BFGS 6	BFGS 9
Activating the hidden layer	Exponential	Identity	Exponential	Exponential
Output activation	Logistic	Exponential	Logistic	Logistic

The construction of models of an artificial neural network was carried out using the statistical software STATISTICA 10 by entering statistical data for 250 points. In order to avoid retraining the network and guarantee high-quality generalization, random separation of observations between samples was carried out. 180 points were used as training, model error testing was carried out at 50 points, and adequacy checks were carried out at 20 points. At the same time, two variants with 12 and 15 input parameters (neurons) were considered. All models had one output parameter (neuron), namely the FD level.

Fig. 5. Graphical interpretation of the calibration of the local area according to the calculated level of fire danger

5. 2. Checking the operability of the methodology for assessing the level of fire danger of a large-scale area

According to the results of analyzing the models in Table 2, it was established that the neural network model MLF 15-5-1 has the smallest error. Training of this neural network was carried out at a speed of η=0.01. Verification of the adequacy of the developed model was carried out by comparing the statistical level of FD at points (the data of which were not used in the training of the neural network $\left(R^{*}_{LT}\right)$, of the results of assessing the level of FD for the same objects (R_{LTi}), and the corresponding correlation coefficients (r^2) (Table 3). The average correlation coefficient between these indicators based on the results of network training is $r^2 \approx 0.97$. However, based on the fact that the range of 10 levels of the initial data is step-by-step from I to X, each step of the error immediately leads to a decrease in accuracy by 10 %.

Table 3

Checking the adequacy of the neural network model MLF 15-5-1

Parameters	Point 1	Point 2	Point 3	Point 4	Point 5
Coordinates	50.016712, 36.102304	49.920210, 35.953989	49.839046, 36.768428	49.595110, 35.819919	50.215436, 36.401900
R^{*}_{LT}	II	V	VI	IV	III
R_{LTi}	II	VI	VI	III	III
r^2	1	0.9	1	0.9	1

Attention should be paid to the results for point 4 (Table 3). As you can see, the error of forecasting results lies within the permissible 10 % but, at the same time, the level of FD is underestimated relative to the real one. This can lead to an underestimation of FD, which is significantly worse than the same error in the direction of revaluation of FD. Therefore, such points need to be monitored to carry out a more thorough analysis. The accuracy of the assessment

6.Discussion ofresults of the development of a methodology for assessing the level of fire danger of a large-scale area

When assessing the FRover LT of a large scale, which goes beyond the boundaries of a particular settlement, other factors become important. These are such factors as population density, the presence and density of the plant layer, the likelihood of LF on the ground, and the network of paths that determines the time of the FRU's heading to the place of F occurrence. Ranking the functional capacity of FRU allows us to compare the level of FDover LT to the number of forces and means that make it possible to reduce such a risk. In this case, the rank indicated in Table 1 does not necessarily have to correspond to a separate FRU, this may be the total rank of all FRUs involved in the extinguishing of LFover LT.Ranking the territory by FD level using the developed methodology allows one to get a complete map of FR of any district. The disadvantages of this approach are the need to collect and analyze a large amount of data, which is a rather labor-intensive task within a large-scale LT. Also, with an increase in rastration, the accuracy of the determination increases but the volume of the required input parameters grows exponentially. Shown in Fig. 4, the spatial distribution of buildings is not a complete analog of the spatial distribution of population density since the number of storeys of buildings is not taken into account.In cities with a population of more than 100 thousand people in which the percentage of high-rise residential development exceeds 10 %, the discrepancy between the density of buildings and population density is significant. For such cities, it will be correct to use the methodology for assessing small-scale FRover LT. For areas with predominant one and two-story buildings, exceeding population density can be neglected. When analyzing statistics on landscape LF, in addition to Global Fire Atlas, there are other resources that can represent information in other formats.Such resources conduct their analysis on the basis of data obtained by the MODIS satellite system. However, different approaches to their analysis make it possible to obtain diverse results. But the analysis of the array of satellite data on landscape LF was not considered in our paper and is the direction of future research. A large number of FR factors of a separate LT point with a dimension of a different nature does not make it possible to build an ordinary mathematical model of the dependence of FR level on individual parameters. The solution to this problembecame possible using neural network learning algorithms. To train the neural network and check its performance, characteristics from 250 objects were used. However, it should be noted that although the obtained neural network makes it possible to obtain prediction results with satisfactory accuracy and correlation index $r^2 \approx 0.97$, the minimum allowable amount of data was chosen for its training. Therefore, further research will be aimed at continuing the training of the developed neural network, which will increase its accuracy and versatility. The use in practice of the proposed approaches to assessing the level of FDover LT of a large scale will allow for assessment of the level of provision of LT with the necessary fire-fighting forces and means.

7. Conclusions

1. We have theoretically substantiated the methodology for assessing fire risk in a local area of a large scale. A feature of the proposed technique is a differentiated assessment of the fire risk at each point of the surface plane. For such an assessment, the parameters that are decisive in terms of the impact on fire danger are analyzed and structured. These factors include the spatial distribution of population density and infrastructure, the transport and communication network, the spatial distribution of the density and type of vegetation, and statistical data on landscape fires. It is possible to use real-time geographic information resources such as Fire Information for Resource Management System, Awesome Gee Community Catalog, Global Fire Atlas, and data from the Moderate Resolution Imaging Spectroradiometer satellite system. A new approach to ranking the fire risk of the elementary plane of the territory in accordance with the required amount of resources of rescue units to ensure an adequate level of safety has been proposed. To compare the parameters of the local territory with the ranks of fire risk, neural network data processing methods were used. A neural network model was obtained capable of comparing the fire risk of the territory to its parameters.

2. The operability of the developed methodology was checked and the levels of fire risk of an arbitrary territory, based on a predictive neural network model, with an average degree of correlation of 0.97, were determined. It has been established that the proposed neural network is capable of self-learning, which makes it possible to clarify the results of the assessment when entering new statistical data. Based on the data obtained, a graphical interpretation of the calibration of the local area according to the calculated level of fire danger was created.That is, using this technique, it became possible to build fire hazard maps and to zone a local area of arbitrary scale. In general, the operability of the proposed methodology for assessing and adjusting the state of providing local territories with civil protection resources has been confirmed. Our methodology acquires particular relevance in the spatial placement of new fire and rescue units of communities.

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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ABSTRACT AND REFERENCES
ECOLOGY

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PRODUCTION OF PHYSIOLOGICALLY COMPLETE DRINKING WATER USING MODIFIED REVERSE OSMOSIS MEMBRANE ELEMENTS (p. 6–13)

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Drinking water prepared using the most effective and popular reverse osmosis method is absolutely safe but for the most part does not meet the requirements for physiologically complete water. The latter must meet, in addition to the basic requirements, the following requirements: salt content, at least 100, and not more than 1000 mg/dm^3; total hardness; in the range of 1–7.0 mmol/dm^3. Now, to fulfill these requirements, the stage after desalting employs various methods of domineralization of reverse osmosis water, each of which has certain disadvantages.

This paper considers the task of obtaining safe physiologically complete water immediately after the stage of membrane desalting by using modified reverse osmosis membrane elements with the predefined selectivity. The study object was the process of obtaining reverse osmosis membrane elements with the predefined selectivity by modifying them with sodium hypochlorite solution for use in the process of obtaining physiologically complete drinking water.

The required level of selectivity of modified elements was calculated to obtain safe physiologically complete water from starting water, depending on its salt content. Thus, for the starting water with a salt content of 200–300 mg/dm^3, the specified selectivity of the membrane element should be no more than 60 % at a temperature of 25 °C. Rational conditions for conducting the modification process for obtaining a membrane element with such exact selectivity have been established. The nature of the influence of changes in water temperature on the selectivity of the modified element was studied.

A prototype of the modified element was tested in a vending machine for bottling water, which purified tap water in the city of Kyiv, with a salt content of 230 mg/dm^3 at a temperature of 8–12 °C. The test results showed the possibility of one-stage obtaining safe physiologically complete water by reverse osmosis using a modified membrane element with the predefined selectivity of 50 %.

Keywords: reverse osmosis, modified membrane elements, predefined selectivity, physiologically complete water.

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COMPARISON OF BICOHERENCE ON THE ENSEMBLE OF REALIZATIONS AND A SELECTIVE EVALUATION OF THE BISPECTRUM OF THE DYNAMICS OF DANGEROUS PARAMETERS OF THE GAS MEDIUM DURING FIRE (p. 14–21)

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The object of the study is the bicoherence of the bispectrum assessment of the dynamics of dangerous parameters of the gas environment during the ignition of materials. The subject is a measure of bicoherence of the bispectrum estimation from the ensemble of realizations and selective bispectrum estimation for the dynamics of hazardous parameters of the gas environment. The practical importance of the research is the use of the measure of bicoherence of the bispectrum for the early detection of fires. The measure of bicoherence of the dynamics of hazardous parameters of the gas environment is substantiated, which allows them to be numerically compared for the studied bispectrum estimates. As such measure, it is proposed to use the integral value of bicoherence for a given frequency interval, which makes it possible to numerically compare the bicoherence of bispectrum estimates for arbitrary time intervals of the dynamics of hazardous parameters of the gas environment. On the basis of the proposed measure for the frequency range of 0.2–2 Hz, a comparison of the integral bicoherence of the bispectrum estimates was made. The numerical value of the measure was determined for three fixed time intervals of the dynamics of hazardous parameters of the environment, corresponding to the absence of ignition, the occurrence of ignition, and the subsequent burning of test materials in the laboratory chamber. According to the results of the comparison of such values, it was established that the bicoherence of the bispectrum estimation from the ensemble of realizations is the most appropriate for detecting fires. When ignited, the numerical value of the measure for all test materials is about 90°. This means that the nature of the dynamics of hazardous environmental parameters in the event of fires becomes random. In this regard, the proposed measure is recommended to be used as a test for early detection of fires.

Keywords: early fire detection, bispectrum assessment, bicoherence, dangerous parameters, gaseous medium.

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DETERMINING THE THERMAL-PHYSICAL CHARACTERISTICS OF A COKE FOAM LAYER IN THE FIRE PROTECTION OF CABLE ARTICLES WITH FOAMING COATING (p. 22–30)

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An issue related to using cable products for building structures is to ensure their stability and durability when operating within wide limits. Therefore, the object of research was a change in the properties of the polymer sheath of the cable during the formation of a swollen coating layer under the influence of high temperature. It is proved that in the process of thermal action on the flame retardant coating, the process of thermal insulation of the cable involves the formation of particulate products on the surface of the sample. Under the action of the burner flame, a temperature was reached on the surface of the sample, which led to a swelling of the coating of more than 16 mm. The measured temperature on the inverse surface of the sample was no more than 160 °C, which indicates the formation of a barrier for temperature. In this regard, a calculation and experimental method for determining thermal conductivity when using a flame retardant as a coating has been developed, which makes it possible to estimate the coefficients of temperature conductivity and thermal conductivity under high-temperature action. According to the experimental data and established dependences, the coefficients of temperature conductivity and thermal conductivity of wood were calculated, which are $214.4 \cdot 10^{-6}$ m^2/s and 0.62 W/(m·K), respectively, due to the formation of a heat-insulating swollen layer. The maximum possible temperature penetration through the thickness of the coating was assessed. A temperature was created on the surface of the sample, which significantly exceeds the ignition temperature of the polymer sheath of the cable, and, on a non-heated surface, does not exceed 160 °C. Thus, there is reason to argue about the possibility of directed adjustment of the fire protection processes of an electrical cable by using coatings capable of forming a protective layer on the surface of the material, which inhibits the rate of heat transfer.

Keywords: fire retardants for cable products, electrical cable, combustion of polymer cable sheath, cable surface treatment, coating.

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LEVEL OF FIRE DANGER OF THE LOCAL TERRITORY (p. 31–38)

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The object of the study is the fire risk of the local area. The problem to be solved is to take into account most of the significant parameters in the territorial placement of fire-rescue units of different functional capacities. As part of the solution to this problem, a technique for assessing the fire risk of a large-scale local area has been developed. The methodology is focused on local territories of a large area with a low population density. A special feature of the proposed method is the differentiated fire risk assessment of each point of the surface plane. For such an assessment, the parameters that are decisive from the point of view of impact on the fire hazard are analyzed and structured. The specified factors include the spatial distribution of population density and buildings, the transport and communication network, the spatial distribution of the density and type of vegetation, and statistical data on landscape fires. The use of existing geo-informational resources in real time is foreseen. A new approach of ranking the fire risk of the elementary plane of the territory in accordance with the necessary number of resources of rescue units to ensure the appropriate level of safety is proposed. Neural network data processing methods were used to compare local area parameters with fire risk ranks. A neural network capable of comparing the fire risk of the territory with its parameters was obtained. The functionality of the developed methodology was tested and the fire risk levels of an arbitrary area were graded with an average degree of correlation of 0.97. The proposed method allows for assessment and correction of the state of provision of local territories with civil protection resources. The developed methodology is especially relevant when creating new fire and rescue units of territorial communities.

Keywords: fire risk, local territory, fire station, service area, neural network, population density.

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DETERMINATION OF FIRE PROTECTION DISTANCES DURING A TESLA MODEL S FIRE IN A CLOSED PARKING LOT (p. 39–46)

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This study modelled an electric vehicle fire on the example of a Tesla Model S (USA) in a closed car park. Such fires pose an increased danger due to their rapid spread, the presence of a large number of vehicles, the release of toxic combustion products and heavy smoke. In fact, the rapid spread of a fire in a closed car park is caused by unreasonably small distances between vehicles. Thus, the purpose of the study was to determine the minimum fire protection distances due to an electric vehicle fire in a closed car park using the example of Tesla Model 3.

For this purpose, the objects and their physical characteristics were described, input and environmental parameters were set, and a mathematical model of the dynamics of fire development was formed. This made it possible to establish the minimum fire protection distance during the free development time of 610 s for an electric vehicle fire in a closed car park, which is 10 m along the flank and 6 m along the front. The difference in fire protection distances on the flank and front is explained by the design features of the electric vehicle. That is, the flank area of the flame will be larger than the front of the burning electric vehicle, and therefore the heat radiation power will also be greater. The actual heat radiation power is the key factor affecting fire protection distances.

The results of the study can be used in the design of various types of car parks and the safe placement of vehicles in them. Fire protection distances between cars in enclosed car parks can be taken

into account by insurance companies when assessing the risk of damage to cars due to fires. And also by fire and rescue units involved in extinguishing such fires, to ensure the safety of rescuers.

Keywords: fire protection distance in a car park, FDS modelling of Tesla Model 3 fire, electric vehicle fire.

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DETERMINING THE POSSIBILITY OF THE APPEARANCE OF A COMBUSTIBLE MEDIUM IN THE HYDROGEN STORAGE AND SUPPLY SYSTEM (p. 47–54)

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The object of this study is the process of functioning of the hydrogen storage and supply system. The issue of fire-explosive events in the hydrogen storage and supply system is investigated. A set of mathematical models has been built to determine the probability of a combustible medium in the hydrogen storage and supply system. This set includes partial mathematical models for the main elements of the system, which are united by a generalized mathematical model. When constructing partial mathematical models, the probabilities of trouble-free operation of the main elements of the system are used, which include a pipeline and a gas generator with a pressure stabilization circuit. The probability of trouble-free operation is represented in the form of two multiplicative components that take into account catastrophic and parametric failures of the main elements of the system. When determining the probability of trouble-free operation of the main elements of the system in relation to parametric failures, the integral (generalized) parameters were used. In particular, for a gas generator, such parameters are its time constants. The current values of time constants of the gas generator are determined according to the developed algorithm whose feature is the use for its implementation of the values of the amplitude-frequency characteristics of the system, which are determined at three a priori given frequencies. For a typical version of the on-board hydrogen storage and supply system, quantitative indicators of the likelihood of a combustible medium are given. It is shown that if the parametric failures of the main elements of the system are not taken into account, an error occurs, the value of which is 30.0 %.

The results could be used to obtain an express assessment of the level of fire hazard of hydrogen storage and supply systems at different stages of their life cycle.

Keywords: hydrogen storage and supply system, combustible environment, catastrophic failures, parametric failures.

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АНОТАЦІЇ

ECOLOGY

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ОТРИМАННЯ ФІЗІОЛОГІЧНО ПОВНОЦІННОЇ ПИТНОЇ ВОДИ З ВИКОРИСТАННЯМ МОДИФІКОВАНИХ ЗВОРОТНООСМОТИЧНИХ МЕМБРАННИХ ЕЛЕМЕНТІВ (с. 6–13)

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Питна вода, підготовлена з використанням найбільш ефективного та популярного зворотноосмотичного методу, є абсолютно безпечною, проте здебільшого не задовольняє вимогам, що висуваються до фізіологічно повноцінної води. Остання повинна відповідати окрім основних також наступним вимогам: солевміст не менше 100 та не більше 1000 мг/дм^3, а загальна жорсткість в діапазоні 1–7,0 ммоль/дм^3. Зараз для досягнення їх виконання на наступній після знесолення стадії використовуються різні методи домінералізації зворотноосмотичної води, кожен з яких має певні недоліки.

В роботі вирішувалась проблема одержання безпосередньо після стадії мембранного знесолення безпечної фізіологічно повноцінної води з використанням модифікованих зворотноосмотичних мембранних елементів з заданою селективністю. Об'єктом дослідження виступав процес одержання зворотноосмотичних мембранних елементів із заданою селективністю шляхом їх модифікації розчином гіпохлориту натрію для використання в процесі отримання фізіологічно повноцінної питної води.

Розраховано необхідний рівень селективності модифікованих елементів для одержання безпечної фізіологічно повноцінної води з вихідної в залежності від її солевмісту. Так, для вихідної води з солевмістом 200–300 мг/дм^3 задана селективність мембранного елементу має складати не більше 60 % при температурі 25 °C. Встановлені раціональні умови ведення процесу модифікації для одержання мембранного елементу з саме такою селективністю. Вивчено характер впливу зміни температури води на селективність модифікованого елементу.

Дослідний зразок модифікованого елементу було випробувано у вендинговому автоматі з розливу води, в якому проводилось очищення водопровідної води м. Києва з солевмістом 230 мг/дм^3 при температурі 8–12 °C. Результати випробувань показали можливість одностадійного отримання безпечної фізіологічно повноцінної води методом зворотного осмосу з використанням модифікованого мембранного елементу з заданою селективністю 50 %.

Ключові слова: зворотний осмос, модифіковані мембранні елементи, задана селективність, фізіологічно повноцінна вода.

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ПОРІВНЯННЯ БІКОГЕРЕНТНОСТІ ПО АНСАМБЛЮ РЕАЛІЗАЦІЙ І ВИБІРКОВОЇ ОЦІНКИ БІСПЕКТРУ ДИНАМІКИ НЕБЕЗПЕЧНИХ ПАРАМЕТРІВ ГАЗОВОГО СЕРЕДОВИЩА ПРИ ЗАГОРЯННЯХ (с. 14–21)

Б. Б. Поспєлов, Є. О. Рибка, Д. Ю. Полковниченко, І. Я. Мисковець, Ю. С. Безугла, Т. Ю. Бутенко, С. В. Гарбуз, Л. А. Прохорова, О. М. Левада, М. М. Кравцов

Об'єктом дослідження є бікогерентність оцінки біспектра динаміки небезпечних параметрів газового середовища під час загоряння матеріалів. Предметом є міра бікогерентності оцінки біспектра з ансамблю реалізацій та вибіркової оцінки біспектра для динаміки небезпечних параметрів газового середовища. Практична важливість досліджень полягає в використанні міри бікогерентності біспектра для раннього виявлення загорянь. Обґрунтовано міру бікогерентності динаміки небезпечних параметрів газового середовища, що дозволяють чисельно їх порівнювати для досліджуваних оцінок біспектра. У якості такої міри пропонується використовувати інтегральне значення бікогерентності для заданого частотного інтервалу, яка дозволяє чисельно порівнювати бікогерентність оцінок біспектра для довільних часових інтервалів динаміки небезпечних параметрів газового середовища. На основі запропонованої міри для частотного діапазону 0,2–2 Гц виконано порівняння інтегральної бікогерентності оцінок біспектра. Чисельне значення міри визначалося для трьох фіксованих часових інтервалів динаміки небезпечних параметрів середовища, що відповідають відсутності загоряння, виникненню загоряння та подальшого горіння тестових матеріалів у лабораторній камері. За результатами порівняння таких значень встановлено, що найбільш доречною для виявлення загорянь виявляється бікогерентність оцінки біспектра з ансамблю реалізацій. При загорянні чисельне значення міри для всіх тестових матеріалів становить близько 90^o. Це означає, що характер динаміки небезпечних параметрів середовища у разі виникнення загорань набуває випадкового характеру. У зв'язку з цим запропоновану міру рекомендовано використовувати як тестову для раннього виявлення загорянь.

Ключові слова: раннє виявлення загорянь, оцінка біспектра, бікогерентність, небезпечні параметри, газове середовище.

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ВСТАНОВЛЕННЯ ТЕПЛОФІЗИЧНИХ ХАРАКТЕРИСТИК ШАРУ ПІНОКОКСУ ПРИ ВОГНЕЗАХИСТІ КАБЕЛЬНОЇ ПРОДУКЦІЇ СПУЧУЮЧИМ ПОКРИТТЯМ (с. 22–30)

Ю. В. Цапко, Р. В. Ліхньовський, О. Ю. Цапко, В. В. Коваленко, О. М. Слуцька, П. О. Іллюченко, Р. І. Кравченко, М. В. Суханевич

Проблема застосування кабельної продукції для будівельних конструкцій полягає в забезпечені їх стійкості і довговічності при експлуатації в широких межах. Тому об'єктом досліджень була зміна властивостей полімерної оболонки кабелю при утворенні спученого шару покриття під впливом високої температури. Доведено, що в процесі термічної дії на вогнезахисне покриття процес теплоізолювання кабеля полягає в утворенні сажоподібних продуктів на поверхні зразка. Так саме під дією полум'я пальника на поверхні зразка була створена температура, що призвела до спучення покриття понад 16 мм. Виміряна температура на оберненій поверхні зразка склала не більше 160 °С, що свідчить про утворення заслону для температури. У зв'язку з цим розроблено розрахунково-експериментальний метод визначення теплопровідності при застосуванні вогнезахисного засобу в якості покриття, що дозволяє оцінити коефіцієнти температуропровідності та теплопровідності при високотемпературній дії. За експериментальними даними і отриманими залежностями розраховано коефіцієнт температуропровідності та теплопровідності деревини, який становить $214{,}4 \cdot 10^{-6}$ м^2/с та 0,62 Вт/(м·К) відповідно за рахунок утворення теплоізолювального спученого шару. Проведено оцінку максимально можливого проникнення температури через товщу покриття. На поверхні зразка створено температуру, що значно перевищує температуру займання полімерної оболонки кабелю, а на необігрівній поверхні не перевищує 160 °С. Таким чином, є підстави стверджувати про можливість спрямованого регулювання процесів вогнезахисту електричного кабелю шляхом застосування покриттів, здатних утворювати на поверхні матеріалу захисний шар, який гальмує швидкість передавання тепла.

Ключові слова: вогнезахисні засоби для кабельної продукції, електричний кабель, горіння полімерної оболонки кабелю, оброблення поверхні кабелю, спучення покриття.

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РІВЕНЬ ПОЖЕЖНОЇ НЕБЕЗПЕКИ ЛОКАЛЬНОЇ ТЕРИТОРІЇ (с. 31–38)

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Об'єктом дослідження є пожежний ризик локальної території. Проблема, що вирішувалась, полягає врахуванні більшості значущих параметрів при територіальному розміщенні пожежно-рятувальних підрозділів різної функціональної спроможності. В рамках вирішення цієї проблеми розроблена методика оцінки пожежного ризику локальної території великого масштабу. Методика орієнтована на локальні території великої площі із низькою щільністю населення. Особливістю запропонованої методики є диференційована оцінка пожежного ризику кожної точки площини поверхні. Для такої оцінки проаналізовані та структуровані параметри, що є визначальними з точки зору впливу на пожежну небезпеку. До зазначених факторів відносяться просторовий розподіл щільності населення та забудови, транспортно-комунікаційна мережа, просторовий розподіл густини та виду рослинності та статистичні данні по ландшафтним пожежам. Передбачено використання існуючих геоінформаційних ресурсів в режимі реального часу. Запропоновано новий підхід ранжування пожежного ризику елементарної площини території у відповідності до необхідної кількості ресурсів рятувальних підрозділів для забезпечення належного рівня безпеки. Для співставлення параметрів локальної території з рангами пожежного ризику використано нейромережеві методи обробки даних. Отримано нейромережу, здатну співставляти пожежний ризик території до її параметрів. Проведено перевірку працездатності розробленої методики та проведено градуювання рівнів пожежного ризику довільної території із середнім ступенем кореляції 0,97. Запропонована методика дозволяє проводити оцінку та корегування стану забезпечення локальних територій ресурсами цивільного захисту. Особливу актуальність розроблена методика має при створенні нових пожежно-рятувальних підрозділів територіальних громад.

Ключові слова: пожежний ризик, локальна територія, пожежна станція, район обслуговування, нейромережа, щільність населення.

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ВИЗНАЧЕННЯ БЕЗПЕЧНИХ ПРОТИПОЖЕЖНИХ ВІДСТАНЕЙ ПІД ЧАС ПОЖЕЖІ TESLA MODEL S НА ЗАКРИТОМУ ПАРКІНГУ (с. 39–46)

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У цьому дослідженні змодельовано пожежу електромобіля на прикладі Tesla Model S (США) на закритому паркінгу. Такі пожежі несуть підвищену небезпеку, через швидке поширення, наявність великої кількості транспортних засобів, виділення токсичних продуктів згоряння та сильного задимлення. Власне швидке поширення пожежі на закритому паркінгу зумовлене необґрунтовано малими відстанями між транспортними засобами. Таким чином визначення мінімальних протипожежних відстаней внаслідок пожежі електромобіля на закритому паркінгу на прикладі Tesla Model 3 стало метою дослідження.

Для цього проведений опис об'єктів та їх фізичних характеристик, задані вхідні параметри та параметри навколишнього середовища, а також сформована математична модель динаміки розвитку пожежі. Це дало змогу встановити мінімальну протипожежну відстань впродовж часу вільного розвитку 610 с, для пожежі електромобіля на закритому паркінгу, яка становить по флангу 10 м, а по фронту 6 м. Різниця протипожежних відстаней по флангу та фронту пояснюється конструктивними особливостями електромобіля. Тобто зі сторони флангу площа полум'я буде більшою, ніж зі сторони фронту електромобіля, що горить, а значить і потужність теплового випромінювання також. Власне потужність теплового випромінювання і є ключовим фактором, що впливає на протипожежні відстані.

Результати дослідження можуть бути використані при проєктуванні різного роду автопаркінгів, та безпечного розміщення у ньому транспортних засобів. Протипожежні відстані між автомобілями на закритих паркінгах можуть враховуватись страховими компаніями при оцінці ризиків пошкоджень автомобілів внаслідок пожеж. А також пожежно-рятувальними підрозділами, які залучаються для гасіння таких пожеж, для врахування, при забезпеченні безпеки рятувальників.

Ключові слова: протипожежна відстань на автопаркінгу, FDS моделювання пожежі Tesla Model 3, пожежа електромобіля.

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ВИЗНАЧЕННЯ МОЖЛИВОСТІ ПОЯВИ ГОРЮЧОГО СЕРЕДОВИЩА В СИСТЕМІ ЗБЕРІГАННЯ ТА ПОДАЧІ ВОДНЮ (с. 47–54)

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Об'єктом дослідження є процес функціонування системи зберігання та подачі водню. Досліджується проблема виникнення пожежовибухонебезпечних ситуацій в системі зберігання та подачі водню. Побудований комплекс математичних моделей для визначення ймовірності появи горючого середовища в системі зберігання та подачі водню. Цей комплекс включає часткові математичні моделі для основних елементів системи, які об'єднані узагальненою математичною моделлю. При побудові часткових математичних моделей використані ймовірності безвідмовної роботи основних елементів системи, до яких віднесені трубопровід та газогенератор із контуром стабілізації тиску. Ймовірність безвідмовної роботи представлена у вигляді двох мультиплікативних складових, які враховують катастрофічні та параметричні відмови основних елементів системи. При визначенні ймовірності безвідмовної роботи основних елементів системи стосовно параметричних відмов використанні інтегральні (узагальнені) параметри. Зокрема, для газогенератора такими параметрами є його постійні часу. Визначення поточних значень постійних часу газогенератора здійснюється згідно із розробленим алгоритмом, особливістю цього алгоритму є використання для його реалізації значень амплітудно-частотної характеристики системи, які визначаються на трьох апріорі заданих частотах. Для типового варіанта бортової системи зберігання та подачі водню наведені кількісні показники ймовірності появи горючого середовища. Показано, що при неврахуванні параметричних відмов основних елементів системи виникає похибка, величина якої складає 30,0 %.

Отримані результати можуть бути використані для одержання експрес-оцінки рівня пожежонебезпеки систем зберігання та подачі водню для різних етапів їх життєвого циклу.

Ключові слова: система зберігання та подачі водню, горюче середовище, катастрофічні відмови, параметричні відмови.