UDC 621.03.9

FORMATION OF MATHEMATICAL APPARATUS OF METHODS OF FIRE AND EXPLOSION SAFETY CONTROL OF LANDFILL

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Abstract: The authors analyze the fire and explosion hazards of solid waste disposal facilities, taking into account current trends in the introduction of biogas (methane) collection and utilization systems. Methane is considered an alternative energy source for power plants. The authors determined the initial and limiting conditions of the mathematical apparatus of the method of combating fire and explosion hazards of solid waste disposal facilities based on the results of analysis and synthesis of factors of occurrence and spread of man-caused danger, existing mathematical models, and methods of counteracting man-caused danger. This is the basis for the further development of appropriate emergency response techniques. During the analysis, the authors found that humidity, the temperature of the landfill (household waste), the presence of sufficient oxygen at some point in time initiate the formation of explosive concentrations of methane in the array and contribute to the spread of hazards in landfills or dumps. The specific weight of the organic component, the value of the density of the array, the height of the landfill affect the process of counteracting the danger, namely the prevention of dangerous events and prevention of emergency from the object to the highest level of distribution (local level), primarily in the first group priorities, such as the number of victims and injured civilians and specialists of the units of the State Emergency Service of Ukraine. The team of authors has defined a system of equations of connection of the existence of the mathematical device taking into account initial and boundary conditions. A system of communication equations is determined taking into account the initial and boundary conditions of the mathematical apparatus, which allows to further develop a control algorithm for emergency response related to fire and explosion hazardous landfills close to settlements.

Keywords: solid waste, fire and explosion hazard, mathematical apparatus, initial conditions, boundary conditions.

ФОРМУВАННЯ МАТЕМАТИЧНОГО АПАРАТУ МЕТОДИКИ ПРОТИДІЇ ПОЖЕЖОВИБУХОНЕБЕЗПЕЦІ ОБ'ЄКТІВ ЗАХОРОНЕННЯ ПОБУТОВИХ ВІДХОДІВ

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Анотація: Авторами в роботі проаналізовано пожежовибухонебезпека об'єктів захоронення твердих побутових відходів з урахуванням сучасних тенденцій впровадження систем збору та утилізації біогазу (метану). Метан роглядається як альтернативне джерело енергії для енергетичних установок. За результатами аналізу та синтезу факторів виникнення та поширення техногенної небезпеки, наявних математичних моделей та методик протидії техногенній небезпеці що викладені в нормативній літературі, науковій періодики за останні роки визначено початкові та граничні умови існування математичного апарату методики протидії пожежовибухонебезпеці об'єктів захоронення твердих побутових відходів, що є основою для подальшої розробки відповідної методики протидії надзвичайній ситуації. У ході аналізу авторами встановлено, що вологість, температура масиву звалищних ґрунтів (побутових відходів), наявність у достатній кількості кисню у певний момент часу ініціюють утворення пожежовибухонебезпечної концентрації метану в масиві та сприяють поширенню небезпеці на полігонах або звалищах за наслідками впливу, як на довкілля, так й людей. Питома вага органічної складової, значення щільності масиву, висота захоронення відходів впливають на процес протидії небезпеці, а саме запобігання виникнення небезпечної події та попередження переростання надзвичайної ситуації з об'єктового на найбільш високий рівень поширення (місцевий рівень), в першу чергу за наслідками першої групи пріоритетності, як то кількість жертв та постраждалих цивільних осіб та фахівців підрозділів Державної служби України з надзвичайних ситуацій. Колективом авторів визначено систему рівнянь зв'язку існування математичного апарату з урахуванням початкових та граничних умов. Система зв'язку дозволяє у подальшому розробити керуючий алгоритм методики протидії надзвичайній ситуації, яка пов'язана з пожежовибухонебезпекою об'єктів захоронення твердих побутових відходів, що наближені до населених пунктів.

Ключові слова: побутові відходи, пожежовибухонебезпека, математичний апарат, початкові умови, граничні умови.

1 INTRODUCTION

Areas of landfills and dumps for solid waste are increasing every year and approaching settlements [1, 2]. Combustion processes are constantly taking place at these facilities. However, the problem of fires and explosions is especially acute. Waste combustion occurs not only on the surface of landfills but also in the depths of waste accumulation masses [3]. The main consequences of the hazard include both the pollution of environmental components, a significant area of their distribution, and a significant number of dead, injured, people with impaired living conditions. Minimization of these consequences is a priority in the activities of the State Emergency Service of Ukraine. Thus, the solution to the problem of ensuring fire and explosion safety of solid waste disposal facilities becomes relevant.

2 ANALYSIS OF LITERATURE DATA AND PROBLEM STATEMENT

Research has shown that the scientific community, for the most part, considers landfills as sources of environmental pollution regularly, as well as as a result of an emergency (emergency) or a hazardous event (NP) related to fire and explosion hazards. In [4] it was noted that an important characteristic in assessing the fire and explosion hazard of solid waste disposal facilities (SMW) is the morphological composition of waste. Some scientists [5, 6] in support of statistics [1, 2] note that the largest category of waste is food and green waste. Food and green waste are raw materials for the formation of biogas (methane), which can burn and explode. SMW are a heterogeneous mixture in which almost all chemical elements are present both in pure form and in the form of various compounds. The most common chemical elements are carbon and hydrogen [7]. Studies [8] showed the pyrotechnic characteristics of SMW samples. In practice, it is impossible to eliminate the combustible component of waste at the landfill. Considering the morphological composition, the authors [5–7] focus on the calorific value of waste to use it as a raw material for the formation of an alternative energy source. The interest in biogas as an alternative energy source is growing every year in the world [8]. The main components of biogas are methane (on average up to 60% of the total composition), carbon dioxide, nitrogen impurities, hydrogen sulfide, oxygen, hydrogen and other gases [9]. But it should be borne in mind that the composition of SMW, which are sent for disposal, is influenced by many factors (climatic conditions, seasonality, living standards, level of secondary raw materials market), which impose restrictions on the reliable and safe production of quality methane in biogas.

Much of the work of scientists is devoted to the study of optimal conditions for the maximum formation of combustible methane gas in the biogas in the burial sites of SMW. In works [10–12] the optimal range of humidity (60–80%), temperatures (35–40 °C for mesophilic activity and 50–65 °C for thermophilic activity) is given. However, compliance with the optimal values of the factors of formation of the maximum amount of methane can increase the emergence of man-made hazards - reducing the stability of the waste mass due to excessive moisture, or the formation of voids due to waste incineration at high temperatures.

The most common causes of fires are an increase in the oxygen content of the waste due to the violation of landfill technology (insufficient sealing or insulation layer, the placement of excessive amounts of waste), the excess of biogas collection. The use of large volumes of water during extinguishing can lead to a portion of the oxygen in the thickness of the waste and enhance the processes of aerobic decomposition – the formation of flammable explosive gas – methane. Studies [13] have shown that the increase in temperature in the SMW array depends on humidity, morphological composition, activated carbon content, density, heat capacity, thermal conductivity and thermal conductivity of waste. Modelling of thermal processes in the waste array shows the patterns of origin and development of combustion processes. Under certain conditions, the rate of heat release of the oxidation reaction of combustible substances may exceed the rate of heat loss, which leads to a continuous increase in the temperature of the substance and its ignition [4].

Forecasting and prevention of fires at landfills, as a factor in reducing stability [14], is extremely difficult due to the different specific heat of waste. Until the fire or smoke came to the surface, it is almost impossible to detect the source of ignition visually [15, 16]. Also, the results of modelling the temperature distribution in the waste massif at different temperatures of the combustion source [17] indicate the impossibility of accurate detection on the surface by contact methods of underground fire. The state of development of phytocenoses can be used as an indicator of underground fire, but, unfortunately, low efficiency. The above-mentioned works emphasize the fire and explosion hazards at the landfills but do not fully disclose the issue of increasing the level of man-made safety.

In works [18, 19] the mathematical apparatus of the method of prevention of emergencies of cascade type of propagation, associated with the landslide of landfills at the landfill with liquidation-intensive technological equipment. The mathematical model consists of analytical equations of dependence of the number of dead, injured, people with impaired living conditions on the physical properties of landfill soils, such as humidity, density, temperature, and technological indicators of existing power equipment. The condition for the existence of the proposed model is a set of initial and boundary conditions for non-outgrowth of the consequences of emergencies outside the object level of hazard distribution, taking into account the maximum amount of methane in the biogas. However, given not only the hazard associated with landfill landslides, but the unresolved part of the problem is also the lack of a comprehensive and effective method of counteracting the emergency associated with fire and explosion of landfill sites close to settlements where fire, the explosion can be considered as the initiating factors of the shift. Thus, there is a need to determine the conditions for the formation of the mathematical apparatus, which adequately describes the process of preventing an emergency or preventing an emergency related to fire and explosion of solid waste disposal facilities for further development of appropriate methods of combating hazard to civilians and specialists of divisions of the Stater Civil Emergency Service of Ukraine.

3 PURPOSE AND OBJECTIVES OF RESEARCH

The work aims to determine the conditions for the formation of the mathematical apparatus of the method of counteracting the emergency associated with fire and explosion hazards of landfil close to settlements.

To achieve this goal it is necessary to solve the following scientific problems:

– to determine the initial and limit conditions of existence of the mathematical apparatus of the method of counteracting the emergency related to fire and explosion hazard of landfill;

– to determine the basic equations of connection of the mathematical apparatus of the method of counteraction the emergency related to fire and explosion hazard of landfill.

4 RESEARCH RESULTS

There are probabilities of occurrence of both hazardous event and emergencies at the landfills, which are characterized by the size of the consequences. Methane, as a component of landfill gas (biogas), is a hazardous factor in the occurrence and spread of fire, explosion – hazardous event or emergency.

Mathematical modelling is the main tool for studying the process of methane generation. To calculate the gas-energy potential of biogas (methane), a significant number of mathematical models have been developed: Tabasaran-Rettenberger, B. Weber, LandGEM, AKG. KD Pamfilova, AM Shaimova and others. The most important factors for the study of methane generation are humidity, morphological composition, active carbon content, density, the temperature in the waste mass, storage height, service life of the object.

The optimal approach to obtaining complete and reliable assessment data, methane generation forecast is to combine the results of mathematical modelling with field research. However, the use of direct field measurement methods is limited. The limitations are due to their complexity and high cost.

Explosives at landfills undergo complex physical, chemical and biological transformations with the release of landfill gas.

The initial volume after unloading the SMW on the burial map is significantly reduced due to self-sealing. To reduce the volume occupied, the waste is compacted with the help of special heavy equipment (bulldozers, rollers) - the density reaches 1 t/m^3. The formed substrate has anomalous geophysical characteristics, anomalous engineering and geological parameters, as well as inhomogeneous filtration properties and poor drainage. The higher the density (microbiological life in such material slows down), the less gas is formed, and the reduction of waste fractions increases gas formation.

Among the chemical processes at the landfills of SMW are redox and photochemical reactions, hydrolysis and depolymerization, the formation of sparingly soluble and complex compounds.

Biodegradation occurs under the action of a large number of microorganisms. The main place is occupied by bacteria, which provide the beginning of the process of decomposition of organic matter and a rapid temperature rise. First, a group of mesophilic bacteria develops, and after heating the waste medium, a group of thermophilic bacteria begins to actively develop, which can break down more stable organic compounds. It should be borne in mind that some chemicals (such as heavy metals) are toxic and inhibitors of microorganisms.

Aerobic decomposition takes place in the upper layers of the burial massif at a depth of 50–80 cm and is usually quite short, as its duration is limited by the amount of oxygen. This stage is characterized by the formation of carbon dioxide, water, nitrates, nitrites, nitrogen, organic residues and large amounts of heat. As the waste is compacted and isolated by the soil, the aerobic phase of microbiological decomposition tends to become anaerobic-aerobic microorganisms go into an anaerobic state. This is caused by insufficient oxygen supply to the waste layer to meet the conditions of the aerobic process.

Anaerobic decomposition is slower and is accompanied by an order of magnitude less heat release. In the hydrolysis phase under the action of bacteria is the decomposition of easily degradable and hydrolysis of cellulose-containing waste. In the acetogenic (acidic) phase – further decomposition of cellulose with the formation of low molecular weight acids, alcohols. The environment in the body of the landfill becomes very acidic. Acids reduce the hydrogen index, which contributes to the decomposition of easily and moderately decomposable waste. Acids together with moisture release nutrients for methane-forming microorganisms. Then comes the methanogenic phase in which the acids formed in the acetogenic phase decompose, with significant methane formation. Over time, the amount of nutrients decreases and the process of methane formation attenuates. Anaerobic microorganisms receive the energy necessary for life as a result of the decomposition of organic matter. The proportion of the organic component of SMW (paper, wood, textiles, plant and food residues) determines the number of micronutrients required for methane-forming microorganisms.

Humidity is a necessary factor for the activity of many microorganisms, including methane-forming ones. The solubility of carbon dioxide in water is higher than the solubility of methane, so the high humidity of SMW increases the methane content in the gas phase. The actual moisture content in the array is determined by the initial humidity of solid waste, measures to comply with disposal technologies.

https://doi.org/10.31650/2618-0650-2021-3-2-18-28

Temperature, like humidity, is a determining factor in bacterial activity. Mesophilic groups of methane-forming bacteria actively work at temperatures up to 40 °C, thermophilic - up to 70 °C. The optimal temperature value for the efficient process of methane formation is in the range of 30–40 °C. The level of gas formation decreases significantly when the value of the optimal temperature changes [12].

Taking into account the analysis of factors contributing to the formation of methane in the landfill gas (biogas), the initial conditions of hazard are described by expression (1):

$$\begin{cases} w(t) = w_0 \\ T(t) = T_0 \\ O_2(t) = O_{2_0}. \end{cases} \tag{1}$$

Thus, the initial conditions are the mathematical apparatus of counteraction to the emergency connected with the fire safety of objects of protection of SMW which are close to settlements, is a set of value of moisture. w, the temperature of the landfill massif (dump) T , the presence of sufficient oxygen O_2, which at a certain point in time t initiate the formation of explosive concentrations of methane in the array and the spread of hazard as a result of exposure.

The boundary conditions for counteracting the hazard are described by expression (2):

$$\begin{cases} C_{start} \le C \le C_{fin} \\ \rho_{start} \le \rho \le \rho_{fin} \\ h_{start} \le h \le h_{fin}\ . \end{cases} \tag{2}$$

Thus, the boundary conditions for the existence of the mathematical apparatus of the method of counteracting the emergency associated with fire and explosion hazards of landfills, close to settlements, is a set of interval values of the specific gravity of the organic component C, density ρ, height of waste disposal h, which affect the process of counteracting the hazard.

Taking into account modern domestic scientific approaches in the field of civil protection of Ukraine and the relevant regulatory framework (Order of the Ministry of Internal Affairs of Ukraine dated 06.08.2018 № 658 «On Approval of Classification Features of Emergencies», National Classifier of Ukraine «Emergency Classifier» DK 019: 2010, Resolution of the Cabinet of Ministers of 24.03.2004 № 368 «On approval of the Procedure for classification of emergencies by their levels»), emergencies are a conditional level of emergency, which is achieved by one or more dominant features, in terms of the level of threat and/or countermeasures of the Stater Civil Emergency Service of Ukraine (CES of Ukraine). The number of negative consequences of the emergency should include: the number of victims q_1 and the number of victims q_2, as a consequence of the priority group; the number of people with impaired living conditions q_3 and the amount of damage caused q_4 – are consequences of the second priority group; emergency zone q_5 and the costs of emergency response q_6 – are consequences of the third priority group.

Given the above, the implementation of emergency response methods related to fire and explosion hazards of solid waste disposal facilities should ensure the absence of damage to both civilians and specialists of the CES of Ukraine. This can be achieved through the development and compliance with effective organizational, operational, informational measures based on the mathematical apparatus – are general equation (3):

$$Q(t) = f(w, \rho, T, O_2, C, h, t). \quad (3)$$

In case $Q(t) = HE$ – the prevention of hazardous event (negative consequences did not occur), analytical equation (3), describes the relationship between the dependence of explosive methane concentration on humidity w, density ρ, temperature T, and the presence of sufficient oxygen O_2, organic component C in the massif of landfill soils (SMW), height h and time t waste decomposition. In case $Q(t) = ES$ – the warning of emergency situation (territory of hazard distribution, expenses for liquidation of consequences, the size of the caused damage, number of dead, victims, persons with disturbance of living conditions did not reach local level), analytical equation (3), describes the connection of dependence of the number of dead and injured persons as a consequence of the first level of priority.

The basic communication equations of the mathematical apparatus of the emergency response method are a system (4), the condition of existence is a set of initial conditions (1) of hazard and boundary conditions (2) to prevent and prevent the spread of hazard associated with physicochemical properties landfill (SMW):

$$\begin{cases} Q_{\text{prev}}(t) = f_{\text{prev}}(w, \rho, T, O_2, C, h, t), \ \text{providing} \ \ q_{1\ldots6} = 0; \\ Q_{war}(t) = f_{war}(w, \rho, T, O_2, C, h, t), \ \text{providing} \ \ q_{1\ldots6}^{ob} \le q_{1\ldots6} < q_{1\ldots6}^{local}, \ q_{1\ldots6} \ne 0. \end{cases} \quad (4)$$

Thus, a system of communication equations is defined taking into account the initial and boundary conditions of the mathematical apparatus, which allows to further develop a control algorithm for emergency response methods related to fire and explosion hazards of landfills close to settlements.

5 DISCUSSION OF RESEARCH RESULTS

According to the results of analysis and synthesis of factors of occurrence and spread of fire and explosion hazards at landfill, set out in the regulatory literature in the field of civil safety, scientific sources, statistical reports, it is established that today there is no effective mathematical apparatus that adequately describes the process of hazardous events and prevention of emergencies related to fire and explosion hazard of these objects, close to settlements. A warning is to prevent an emergency from escalating from an objective to the highest level of distribution (local), primarily as a result of the priority group, such as the number of victims and injured.

SMW storage facilities are so-called biochemical reactors, in which landfill gas (biogas) is formed due to anaerobic decomposition of the organic component. The bulk of biogas is made up of gases - methane and carbon dioxide. Methane is a more hazardous component in terms of solving civil security problems. Fire and explosive gas collection and utilization systems are widely used in landfills or dumps. However, it should be additionally taken into account that the process of decomposition of the organic component of SMW takes place unevenly with different intensities: aerobic decomposition with the release of carbon dioxide may predominate on one part of the object, and intensive methane on the other. Oxygen binds carbon and prevents the formation of methane.

Management of waste decomposition processes based on the regulation of physical and chemical properties of landfills (SMW) helps to reduce man-made hazards. It is not always advisable to implement technologies for the collection and utilization of biogas at landfills, while the issue of fire and explosion safety remains relevant. When choosing the appropriate technology to reduce the risk of landfills, it is necessary to take into account: morphological composition - the percentage of the organic component; time and height of burial; guarantees of waste delivery (their composition and quantity); distance to the electrical network; availability near the final consumer for direct use of biogas; oPortunity for capital and operating costs for technology implementation; availability of suppliers of equipment and services; availability and qualification of operators for operation and maintenance of equipment.

In the course of the research, a mathematical basis for the development of emergency response methods related to fire and explosion hazards of landfills close to settlements, the implementation of which will prevent hazardous event or warning emergencies - to limit the spread of hazard from the object level to more high (local), to protect civilians and specialists of the CES of Ukraine from damage.

6 CONCLUSIONS

1. The initial and limiting conditions of existence of the mathematical apparatus of the method of counteraction the emergency related to fire and explosion hazard of of landfill are defined. The initial conditions for the existence of the mathematical apparatus of the emergency response method associated with fire and explosion hazards of solid waste are the conditions of man-made hazards that change over time, namely humidity, the temperature of landfill (solid waste), the presence of sufficient oxygen at a certain point in time initiate the emergence of hazard – the formation of explosive concentrations of methane in the array and the spread of hazard as a result of exposure. The limiting conditions for the existence of the mathematical apparatus of the emergency response method are the conditions for preventing and preventing the spread of man-made hazards, namely the specific weight of the organic component, the density of the array, the height of waste disposal affect the hazard response process. The above list is sufficient to address issues of civil safety – combating fire and explosion hazards of landfill, to protecting civilians and specialists of the Civil Service of Ukraine for Emergencies.

Scientific work is further aimed at establishing the area of effective solutions for the selection of variations of solutions of individual problems to assess these indicators of the initial and boundary conditions of the mathematical apparatus in the development of aPropriate methods.

2. The system of communication equations is defined taking into account initial and boundary conditions of existence of the mathematical device that allows developing further the control algorithm and the technique of counteraction the emergency related to fire and explosion hazard of landfills close to settlements. The process of counteracting the emergency includes a set of measures aimed at preventing the occurrence of fire-explosive concentrations of methane, and with the already existing hazard to limit the number of injured and dead.

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Для посилань:
Рашкевич Н. В., Пастухова А. А., Коновал В. М., Словінський В. К. Формування математичного апарату методики протидії пожежовибухонебезпеці об’єктів захоронення побутових відходів. Механіка та математичні методи, 2021. Т. 3. №. 2. С. 18–28.