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# PRINCIPLES OF CHOOSING A VENTILATION MODE THAT REDUCES THE RISK OF THE DEVELOPMENT OF AN AEROLOGICAL EMERGENCY (ON THE EXAMPLE OF A METHANE EXPLOSION)

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**Abstract.** There are no methods for assessing all parameters of methane explosion when it is in the process, so there is a high risk of untimely undertaking of measures to prevent and eliminate the explosion. In addition, the sensors for measuring parameters of the mine atmosphere included in the existing control systems do not control the lower limit of the explosive concentration of methane.

The purpose and tasks of the research are formulated. The methods by which these problems will be solved are determined.

The concept of direct and indirect emergency risk factors is formulated. Namely: the direct factors of the risk of a methane explosion are the probability of an emergency occurrence and the material damage caused by it. Indirect factors are characteristics of the emergency that can be predicted or calculated during its development. Direct factors for calculating the risk of an event are not suitable for assessing the risk of an explosion, as they cannot be determined in advance. Standard methods of risk assessment are not always sufficiently justified (it is difficult to explain to the average user the difference in the probability of danger of $10^{-6}$ and $10^{-5}$ - both are simply small), while methane accumulation, erroneous actions of the operator, etc. will be much clearer. That is, the use of indirect risk factors is more justified.

The requirements are formulated to which ventilation regime must satisfy during the elimination of an exogenous fire, which is dangerous due to the complication of a methane explosion.

A technique for optimizing the emergency ventilation mode suitable for use in these conditions is presented, and some aspects of its use are discussed. Having formulated the problem in a precise mathematical formulation, that is, having chosen a functional for minimization and having described the requirements for their solution in the form of constraints, it is possible to obtain, using a personal computer, the values of air-gas distribution during the period of explosion elimination, which satisfy the requirements of the Safety Rules in coal mines, which in the same time feasible with the main ventilation fans existing in the mine. However, it is not always possible to get a solution. For the final solution of the problem, it is necessary to involve other methods and means of ventilation control (ventilation doors, local ventilation fans, etc.).

**Keywords**: emergency, explosion of methane and explosive gases, method of optimizing the emergency ventilation mode, direct and indirect factors of the emergency risk.

## 1. Introduction

Many works of Ukrainian and foreign researchers are devoted to the issue of reducing the explosive risk in the coal mines, studying the processes of occurrence and flow of methane and coal dust explosions, and reducing the risk of their consequences [1–8, etc.], especially should be mentioned the works of S.P. Mineev, V.K. Kostenko, A.F. Bulat. They concluded that the current state of the problem of air-gas control of the mine atmosphere in a coal mine is that the sensors for measuring the parameters of the mine atmosphere, which are included in the existing control systems, do not control the lower limit of the explosive concentration of methane, do not provide the necessary control speed, which leads to a sudden explosion of methane. Each explosion of methane in the mine workings indicates that the mine air in this area has an explosive concentration, and in the places where it appeared, there was an igniter of this concentration.

The source of the explosion can be known, but the time of the occurrence of the explosive concentration, the coordinates of the initial place of its occurrence, the speed of its spread and other parameters of the development of the emergency are unknown, since no technical means of control have been developed, including high-speed alarms for exceeding the safe concentration of methane in the mine atmosphere. In addition, there are no methods for assessing the parameters of the emergency, so there is a high risk of untimely measures being taken to prevent and eliminate the explosion of methane and other explosive gases. The development of such methods is of great importance for reducing the risk of its occurrence and eliminating undesirable consequences.

**The purpose** of the article is a brief description of the method of reducing the risk and spreading the explosion of a gas mixture in the center of fire.

According to this purpose, the following **tasks** should be solved:

a) to ensure an access (at least one) of a clean ventilation stream to the center of fire;

b) to ensure the flow of air in the places of possible accumulation of combustible gases near the source of spark and flame formation sufficient to guarantee the explosion safety of the gas-air mixture with the necessary degree of reserve;

c) to ensure the air flow in the workings of the emergency zone, the minimum possible spread of fire and, thereby, the risk of complicating an explosive situation.

## 2. Methods

Methods of approximate calculations, mathematical programming, risk theory, theory of fuzzy sets and fuzzy logic will be used to solve the problems. Experimental studies will be conducted on control examples.

## 3. Theoretical part

Direct factors for calculating the risk of an event (the probability of its occurrence and the magnitude of the consequences) are unsuitable for assessing the risk of an explosion, as they cannot be determined in advance. Therefore, in order to reduce the risk, it is necessary to move to risk assessment based on indirect factors that do not have a probabilistic form. The use of such indirect factors is the goal of solving the problem of improving the assessment of the emergency risk of an explosion. This is the novelty of the proposed approach. Standard methods of risk assessment are not always sufficiently justified (it is difficult to explain to the average user the difference between the probability of danger of $10^{-6}$ and $10^{-5}$ - both are simply small), while methane accumulation, erroneous actions of the operator, etc. will be much more understandable. That is, the use of indirect risk factors is more justified.

Their optimal values obtained according to a certain criterion will correspond to the minimum risk value. Their use provides a *qualitative assessment* of risk, contributing to the subsequent *quantitative assessment* of risk (although they do not provide an opportunity to obtain a specific value of the latter).

The most widespread and at the same time the most dangerous type of underground emergencies is fire. Occurred in the limited space of the working, it is capable to disrupt the normal ventilation of the mine in a short period of time. Thermal depression initiated by the fire in a number of cases reaches and exceeds the value created by the main ventilation fans (MVF) in sloping workings with downward ventilation. Being directed towards ventilation flow thermal depression causes the overturning of the ventilation jet in such workings and the unexpected gassing of the mine ventilation network with gaseous combustion products. Even in cases where the described phenomenon does not occur, toxic gaseous products, spreading in accordance with the direction of air streams, are able to create the false images of people working in the mine. In addition, there is a danger of catching fire of cut coal located in workings or even coal from pillars or seams, which leads to the loss of useful mineral, long-term failure of the mine and additional economic losses due to the occurrence of an endogenous fire.

Also dangerous is the fact that at a certain stage of fire development, there is a probable risk that it may become the source of an equally complex emergency - a sudden explosion of methane. The study of the interaction and mutual influence of these two types of accidents is of some interest.

In accordance with [9], two main stages of the development of an exogenous fire can be distinguished:

a) ignition (until the moment when the temperature in the center of the fire stops rising and a constant amount of fuel is burned in equal intervals of time);

b) the fire that is developed.

Obviously, at the first stage, a methane explosion is hardly possible. Its duration is determined by the small amount of combustible material in the center of the fire, the insignificance of the thermal depression, etc. At this time, there are the most favorable conditions for solving the priority anti-emergency tasks of the emergency elimination plan (EEP) regarding the emergency evacuation of people and elimination of the emergency in the initial stage. The second task may be or may not be solved at this stage - it is determined by many factors: untimely detection of the emergency (the fire has time to develop), the lack of safe approaches to the center of the fire, and, most importantly and dangerously, the occurrence of an emergency with complications (explosions of methane and other flammable gases). For these cases, it is envisaged to compile and use an operational EEP. It is at this stage that one can effectively calculate the impact of implicit explosion risk factors - because a person operates with such concepts, but not probabilities.

In the event of an emergency and during part of the initial period of its development (including the explosion of methane and other flammable gases), there is a normal ventilation regime in the mine. In the future, it is adjusted in accordance with [10], ensuring the minimum number of people at the emergency site and effective ways of their evacuation. Generally speaking, at this stage it does not affect the elimination of the emergency. Ventilation maneuvers during this period are simple: maintaining the normal mode of ventilation with the same air flow rate, reversing all (or, in some cases, some) MVF or creating "zero ventilation" (exceptionally). Changes in the air flow in the direction of both increase and decrease are impractical. The increase will undoubtedly contribute to the reduction of the concentration of gaseous products in the working of the emergency area (and therefore to the reduction of explosiveness), but at the same time it changes the velocity field and increases the dynamics of the fire area, which has a negative impact on the formation of evacuation routes for people. The decrease, although it does not lead to the creation of an explosive concentration of a mixture of combustible gases (the fire did not develop, gas release (except for methane) is insignificant, the surface of the open flame is limited), increases it, which can cause serious poisoning of people even when self-rescuers are used.

During the period of operation of the operational EEP, it is advisable to move from the mathematical definition of risk to the assessment of the impact of its indirect factors. Criterion [10] is not applicable - there are no people in the mine. The requirements that the ventilation mode must satisfy at this time, provided that any method of fire extinguishing (active, isolation, combined) is used, is reduced to the following:

a) the ventilation mode must ensure the availability of an approach (at least one) to the fire cell with a clean ventilation stream for direct impact on it with fire extinguishing agents (in the case of an active method of extinguishing) or isolation of the fire center from active workings with special isolation structures (for the purpose of isolation and in the case of combined extinguishing methods). If this requirement is not met, the risk of complicating the emergency is quite large (mathematically almost equal to 1), and in order to reduce it, it is necessary to provide for additional implicit risk reduction factors in the operative EEP (for example, the construction of insulating jumpers at some distance from the fire center, additional ventilation measures with using means of local control of ventilation, etc.);

b) the flow of air in places of possible accumulation of combustible gases near the source of sparks and flames must be large enough to guarantee the explosive safety of the gas-air mixture with the necessary margin;

c) the flow of air in the workings of the emergency zone must ensure the minimum possible spread of fire.

**4. Results and discussion**

Based on the three requirements above, the method of optimizing the emergency ventilation mode generally takes the following form:

1. The ventilation mode used during the operational time of the EEP, i.e. up to complete evacuation of people from the mine, is analyzed. If requirement a) is met, satisfaction of requirements of b) and c) is checked.

2. If the requirement a) is not met, the ventilation modes that can be implemented at the moment are reviewed in order to choose a suitable one. It should only be taken into account that in the case of high methane abundance in the workings, the reversal should be preceded by a study of the conditions under which a burst of methane may occur; if the burst cannot be avoided, the existing ventilation mode should be maintained, even though it contributes in a number of cases to the activation of combustion and the increase of the risk of explosion.

3. An analysis of the content of combustible gases in the fire area is carried out, and using Le Chatelier's formula [11] or table data [9], a triangle of explosive safety of the gas-air mixture is constructed.

4. The explosiveness of the specified mixture is analyzed. If the mixture is explosive - an additional air flow to the fire center necessary for the mixture to go beyond the explosive triangle is calculated according to the method [9]. Otherwise, the excess amount of air is calculated, the reduction of which will not lead to explosive safety of the mixture, but will ensure more effective satisfaction of requirement c). This is a rather risky measure that is effective only in the presence of feedback from the fire center in order to provide immediate information on the state of explosive safety. And for this, it is necessary to use the appropriate instrument base, which is not always available at the mines.

5. Based on the obtained gas-air mixture consumption value, its speed in the fire center of the working is calculated.

6. Based on the value of this speed, the main parameters of the fire are determined: the temperature in the center and the speed of its movement.

7. In accordance with [9], the new content of combustible gases in the fire station is determined depending on the temperature. The calculation is repeated starting from paragraph 3.

Studies showed that the iterative process of paragraphs 3-7 is similar and the solution can be continued until the results of the next two iterations coincide with a sufficient degree of accuracy.

8. Based on the required amount of air calculated in paragraphs 3-7, the new amount of air in the MVF is determined taking into account the fact that its proportional change in all MVFs does not change the qualitative picture obtained in paragraphs 1 and 2 [12].

It should be noted that in paragraph 3, it is necessary to make an analysis of the content of combustible gases, specific for each fire, which cannot be done with the early use of a personal computer. Some averaging of the data, which shifts the coordinates of the triangle of explosive safety, can be compensated by a less rigid task of the accuracy of the calculation from paragraph 4.

At the same time, the analysis performed in order to establish the suitability of the methodology for determining the coordinates of the triangle of explosive safety proposed in [9] for performing calculations using a personal computer revealed that the methodology needs some improvement. Namely, the statement regarding the necessity of rounding the calculated proportion of each gas in the mixture to 0.1 for further use in order to find the coordinates according to the special table given in [9], turns out to be unfair in some cases. For example, if the fire area contains 4.5% of $CH_4$; 5.0% of CO and 5.1% of $H_2$ (the sum of them is 4.5 + 5.0 + 5.1 = 14.6), the proportion of each gas in the mixture is

$$P_1 = \frac{4.5}{14.5} \approx 0.3;$$

$$P_2 = \frac{5.0}{14.6} \approx 0.3;$$

$$P_3 = \frac{5.1}{14.6} \approx 0.3.$$

The checksum shows a sum value of 0.9 instead of 1.0, and the table cannot be used. Therefore, the accuracy of 0.1 in the calculation of the coordinates of the triangle of explosive safety is insufficient. It is impossible to increase it, since the tabular data are not calculated for this (the content of combustible gases in the mixture is given with an accuracy of 0.1). In this regard, in the case of coincidence of two or more particles (deviation of the total value from 1.0 is possible only by 0.1 in either direction), the maximum percentage content is selected and the missing 0.1 is added to the corresponding fraction. The overall calculation error is small, since the described error is observed only in the case of sufficiently close percentage values of the components of the explosive mixture, which is observed in a small number of cases.

Having formulated the problem in a precise mathematical formulation, that is, having chosen a functional for minimization and having described the requirements a)-c) in the form of restrictions, it is possible to obtain, using a personal computer, the value of air-gas distribution during the period of fire elimination, satisfying the requirements [13], which at the same time can be implemented by the existing in the MVF. However, as it is mentioned above, it is not always possible to get a decision. To obtain it, it is necessary to involve other methods and means of ventilation control (ventilation doors, local ventilation fans, etc.).

At the end of the presentation of the material, I would like to mention the interesting, in our opinion, recent works of Yu.M. Kaminin. [for example, [14] and others]. They considered various aspects of methodical and instrumental control of the methane explosion process. Without the possibility of a detailed review of the obtained results, one can only note their value, subject to implementation, for reducing the risk of methane explosions in coal mines, possibly in Ukraine as well.

## 5. Conclusions

As a result of the performed preliminary studies, the algorithm and basic provisions of the method for solving the tasks set in the article were developed.

A more in-depth study of implicit factors in the assessment of emergency risks of an explosion at various dangerous underground production facilities can be considered a research prospect, since the assessment of emergency risks with their help can be considered simpler and more understandable for the user, while maintaining the rigor of the statements and the validity of the results obtained. It is necessary to formalize the complex and mathematically solve the three problems set above, taking into account the additional research conducted.

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## ПРИНЦИПИ ВИБОРУ ВЕНТИЛЯЦІЙНОГО РЕЖИМУ, ЗНИЖУЮЧОГО РИЗИК РОЗВИТКУ АЕРОЛОГІЧНОЇ АВАРІЇ (НА ПРИКЛАДІ ВИБУХУ МЕТАНУ)

***Кокоулін І., Сапунова І.***

**Анотація.** Під час протікання вибуху метану відсутні методи оцінки усіх його параметрів, тому існує високий ризик несвоєчасного прийняття мір щодо попередження та ліквідації вибуху. Крім того, датчики виміру параметрів шахтної атмосфери , що входять до існуючих систем контролю, не контролюють нижню межу вибухової концентрації метану.

Сформульовано мету і задачі досліджень. Визначено методи, якими вирішуватимуться ці задачі**.**

Сформульовано поняття прямих і непрямих чинників аварійного ризику. А саме: прямими чинниками ризику виникнення вибуху метану є імовірність виникнення аварії і нанесені нею матеріальні збитки. Непрямі чинники – характеристики аварії, які можуть бути прогнозовані або розраховані у ході її розвитку. Прямі чинники розрахунку ризику події для оцінки ризику вибуху непридатні, оскільки не можуть бути завчасно визначені,. Якщо стандартні методи оцінки ризику не завжди достатньо обґрунтовані (важко пояснити пересічному користувачеві різницю ймовірності небезпеки $10^{-6}$ і $10^{-5}$ - обидві просто малі; значно зрозумілішим буде накопичення метану, помилкові дії оператора тощо). Тобто використовування непрямих чинників ризику є більш виправданим.

Сформульовано вимоги, яким повинен задовольняти вентиляційний режим у період ліквідації екзогенної пожежі, небезпечної за ускладненням вибуху метану.

Представлено методику оптимізації аварійного вентиляційного режиму, придатного для використовування у цих умовах, і обговорено деякі аспекти її використання. Сформулювавши задачу у точній математичній постановці, тобто вибравши функціонал для мінімізації і описавши вимоги до їх вирішення у вигляді обмежень, можна отримати з використанням персонального комп'ютера значення повітрогазорозподілу у період ліквідації вибуху, що задовольняють вимогам Правил безпеки у вугільних шахтах, яке у той же час здійсненне існуючими у шахті вентиляторів головного провітрювання. Однак рішення можливо отримати не завжди. Для остаточного вирішення задачі необхідно залучення інших методів і засобів керування провітрюванням (вентиляційних дверей, вентиляторів місцевого провітрювання тощо).

**Ключові слова:** аварія, вибух метану і вибухових газів. методика оптимізації аварійного вентиляційного режиму, прямі і непрямі чинники аварійного ризику.