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Fundamentals of forecasting explosive gas accumulation formation in working areas of coal mines

Danil Pekarchuk[1*], *Igor* Skripnik[1], *Sergey* Panov[3], *Tatyana* Kaverzneva[4], and *Olga* Gorbunova[5]

[1]Saint - Petersburg University of the State Fire Service of the Ministry of Emergency Situations of Russia, Saint Petersburg Russia
[3]Saint-Petersburg State University of Industrial Technologies and Design, Bolshaya Morskaya str. 18-A., 191186 Saint Petersburg, Russia
[4]Higher School of Technosphere Safety of Peter the Great St. Petersburg Polytechnic University, 29, Politekhnicheskaya st., 195251 Saint Petersburg, Russia
[5]Saint-Petersburg State University of Architecture and Civil Engineering, Department Technosphere Safety Vtoraya Krasnoarmeiskaya st. 4, 190005 Saint Petersburg, Russia

Abstract. This article presents a methodological approach to solving the problem of predicting local methane accumulations in order to prevent occupational injuries resulting from explosions of methane-air mixtures. On the basis of the analysis of accidents that occurred in coal mines and industrial injuries of miners (mine workers) it is established that the leading role belongs to explosions of methane-air mixtures. The method/methodology considered in the article is based on a comprehensive analysis, first of all, of both mining and geological and other influencing factors and conditions of operating mines of the Pechersk coal basin, as well as aerogas-dynamic processes of mass transfer of air flows in mine workings. The assumption about influence of mining equipment on the process of formation of methane accumulation sites is made. The algorithm of consecutive actions of managerial engineering and technical personnel to reduce industrial injuries is proposed. The developed algorithm implies the use of applied software for modelling aerogas-dynamic processes in the mining excavation operating region. FlowVision and ANSYS Fluent application software packages were selected to determine the methane accumulation locations based on the analysis of existing application programmes.

1 Introduction

Coal mines belong to the category of hazardous production facilities, where the greatest danger is posed by explosions of methane-air and/or dust firedamp. The characteristic feature of such accidents is the consequences in the form of group accidents, characterised by a large

* Corresponding author: 79213258397@mail.ru

number of fatally and seriously injured workers and accompanied by significant material damage [1-2].

Due to the increase in the danger of mining operations on the gas factor, caused by the increase in the depth of development, the rate of mining of minerals, the increase in the gas content of formations and, as a consequence, the gas content of workings, etc., there is a need to develop special additional measures to ensure the safety of mine workings on the gas factor. We believe that these measures should be based on early assessment of places of possible local methane accumulations and their control to ensure safe working conditions in mining excavation operating region (hereinafter MEOR). The relevance of the development of such additional measures is confirmed by analysing the materials of investigations of accidents related to explosions in coal mines. According to the annual reports of Rostechnadzor, one of the main causes of firedamps (FD) was the formation of previously undetected accumulations of methane [1, 3-4].

In connection with the introduction of risk-oriented approach, we consider it advisable to take into account the possibility of formation of local zones with increased concentration of methane as a source of danger. For this purpose, among the mining factors, it is necessary to assess the impact on the formation of methane accumulations. When carrying out such an assessment, modelling of ventilation processes is one of the promising directions in mining aerogasodynamics. This will increase the reliability of detection and subsequent control of methane accumulation sites in the space of mine workings [5-6].

The analysis of places of detection of combustible gases accumulation, primarily methane, with increased concentration shows that the rational method of fulfilling the requirements of labour protection and industrial safety in the process of mining operations is the advance forecast of the dynamics of formation of gas hazardous accumulation zones [7-9].

At the same time, methods of direct measurement of concentrations of fire hazardous explosive mixtures (hereinafter FHEM) in the mine workings often cannot be applied due to the difficulty of access and the possibility of disturbing the structure of concentration fields during measurement [10-11]. On the basis of the above stated we consider that the increase of reliability of results of aerogas situation control by means of modern monitoring means is an urgent task. In addition, the solution of this problem will also contribute to the increase in the efficiency of management of the process of ventilation of mine workings and, first of all, of mining areas and will lead to an increase in the safety of coal mine life on the gas factor [5, 12].

2 Materials and methods

The purpose of the work was to develop the basis for predicting the formation of FHEM in the space of mining workings.

To achieve this goal, at this initial stage of our research work, the conditions of formation of local accumulations of explosive gases in mine workings were chosen as the object of study. At the same time, the subject of the study were ways and methods of prevention of industrial injuries based on the prediction of formation and timely control of local methane accumulations.

To achieve the goal, we applied a comprehensive approach, including a set of research methods used to ensure industrial safety of coal mines. It provides for the application of analytical, theoretical and experimental, as well as comparative methods of scientific research [13-15]. These methods are implemented with the help of multifunctional safety systems installed at each coal mine according to the requirements of the Russian legislation [16-17].

To collect the necessary input data for the scientifically-based selection of the application computer programme and construction of the model of mass transfer of mine air containing FHEM, we studied both the data of aerogas control systems and individual control devices, as well as the logs of mine workings gassing of specific coal mines. At one or another stage the authors of the work to collect the necessary data conducted field experiments, including aerogas-air surveys within the mine workings. Field experiments were carried out at several coal mines of the Pechersk coal basin. After determination of initial data and their sufficiency we started computer modelling on applied software complexes [7, 11].

We believe that the use of computer modelling methods will allow us to perform a number of tasks on the preliminary assessment of the gas-air environment in the space of excavations of coal mines and to predict the places of formation of local accumulations of methane in explosive concentrations.

3 Discussion and Results

Based on the collected research data, as well as the results of the analysis of the requirements of the current legislative and regulatory acts governing the issues of labour protection and industrial safety, allowed us to identify a number of problems in the field of prevention of both occupational injuries and mine explosion safety. Thus, for example, we believe that in order to ensure labour safety of coal mine personnel in conditions of FD accumulations in working areas of mine workings it is necessary to develop a normative method of early identification of places of formation of increased concentrations of FHEM for their subsequent continuous monitoring. In addition, it is necessary to develop additional organisational and methodological measures, both for occupational health and safety, for timely notification of workers about specific locations of hazard sources, methods of forecasting their formation and development, as well as prevention of FHEM fire/explosion and reduction of consequences of the impact of hazardous factors of explosion of local FD accumulation [13, 17-18].

In the course of research work, we found that to date the main activities and methods of normalising the atmosphere of coal mine workings include: ventilation of underground mine workings, degassing of coal seams and control of the mine atmosphere with the help of aerogas control equipment included in mine multifunctional safety systems. We agree that professional and high-quality performance of these measures to control the atmosphere of mine workings allows in some cases to prevent the development of incidents and accidents and save the maximum number of miners. However, despite the fact that the use of these methods of normalisation of mine workings atmosphere makes a significant contribution to mine safety, we believe that they are insufficient to achieve due to the possibility of formation of local accumulations of methane and the lack of tools for its early detection. This, in turn, in case of violation of requirements to the conduct of technological and production process, lack of informing the mine personnel about the rules of behaviour when being near or in the FD, as well as other factors can lead to emergencies of varying severity and consequences [2, 3, 19].

Taking into account the above stated, we believe that in order to develop the basis for predicting the formation of FHEM accumulations in MEOR, aimed at preventing occupational injuries of miners it is necessary to study the methods of control, primarily manual measurement, of methane concentrations adopted in the mine and adjust their performance taking into account the shortcomings we have identified in the manual measurement of methane concentrations in the space of mine workings. This is a very important point, because to ensure the safety of mining operations and protection of miners it is necessary to obtain the most reliable information about the distribution of accumulation fields and the value of methane concentrations in them

In case of improper (incorrect) work on manual measurement there is a probability of measuring a random value of methane concentration in the working zone of mine workings. This is due to the fact that the ratio between the area (length) of the accumulation and the area (length) of the zone with maximum concentration can vary widely. When conducting in-situ studies, the anthropometric indicators of the metering person, such as arm span or height, differ from the gradation length of the zone with maximum methane concentration (Fig. 1).

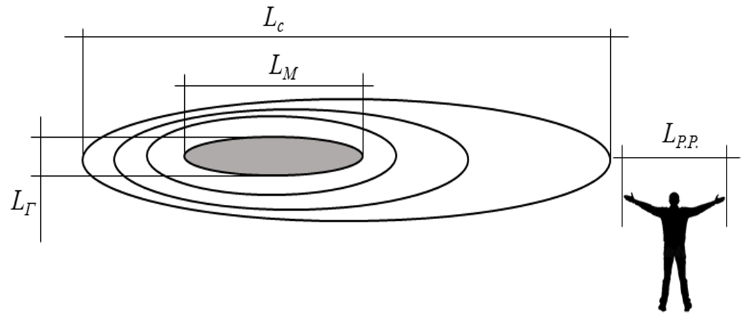

Fig. 1. Example of manual measurement of methane concentration in aggregate formation: L_M – length of the zone with maximum methane concentration, m; L_A – length of methane accumulation, m; L_G – length of maximum accumulation gradation, m; $L_{A.S.}$ – measuring arm span, m.

The probability of measuring the required concentration value is determined by the formula (1):

$$B_3 = P_1 \cdot P_2 = \left(\frac{L_M}{L_A}\right) \cdot \left(\frac{L_Г}{L_{P.P}}\right) , \quad (1)$$

here B_3 is accuracy probability; P_1 – probability of entering an area with maximum methane concentration; P_2 – probability of accurate measurement; L_M is length of the zone with maximum methane concentration, *м*; L_A – methane accumulation length, *m*; L_G – gradation length of the maximum cluster, *m*; $L_{A.S.}$ is measuring arm span, *m*. Provided that the value of P_2 is greater than or equal to 1, then for calculation it is necessary to take $P_2 = 1$.

Table 1 summarises some of the results we have obtained in assessing the accuracy of FHEM measurements. The averaged parameters of local clusters are given as input data.

When conducting the research, the average arm span of the measurer (his anthropometric parameters) was assumed to be 1.8 metres.

Table 1. Results of the accuracy assessment of measurements at aerogas control sites

Excavation (accumulation point)	**Average gradation size of the maximum concentration, L_G (m)**	**Average size of the zone with maximum concentration, L_M (m)**	**Average cluster size, L_A (m)**	**Probability of accurate measurement, B_3**
Blind drift	0.4	2.1	4	0.12
Belt entry	1.3	1.5	6.1	0.18
Back entry	0.5	1.1	2.9	0.1
Cross slit	0.2	0.9	1.3	0.07

Thus, it can be seen that inaccurate measurements are likely to occur during the measurement process. This, in its turn, can lead to an unreliable picture of the mines' contamination. It is also necessary to take into account that interference with the concentration fields contributes to their erosion in view of the subsequent distortion of the picture of mine contamination, i.e. there is a need for a control method that does not have a physical effect on the local concentration and does not contribute to its erosion.

At the last stage of our work on this problem was mathematical modelling of aerogas-dynamic processes of formation of local accumulations of methane.

Due to the fact that at the majority of objects of mining operations for the solution of certain tasks, including those of scientific nature, three professional programmes are mainly used: "Computational Fluid Dynamics (CFD)-complex FlowVision", "SolidWorks" and ANSYS Fluent [2, 11, 12]. According to the preliminary results of modelling, one of which is presented in Figures 2, we determined that the most suitable for solving the problems we face are software packages FlowVision and ANSYS Fluent. In this case, FlowVision is in our opinion simpler in terms of speed of mastering and acquiring skills to work with this complex than ANSYS Fluent. It should also be noted that depending on the tasks at hand, the basic knowledge of a mining engineer may not be sufficient and additional training related to modelling of FHEM mass transfer processes in the space of mine workings in these application software packages will be required.

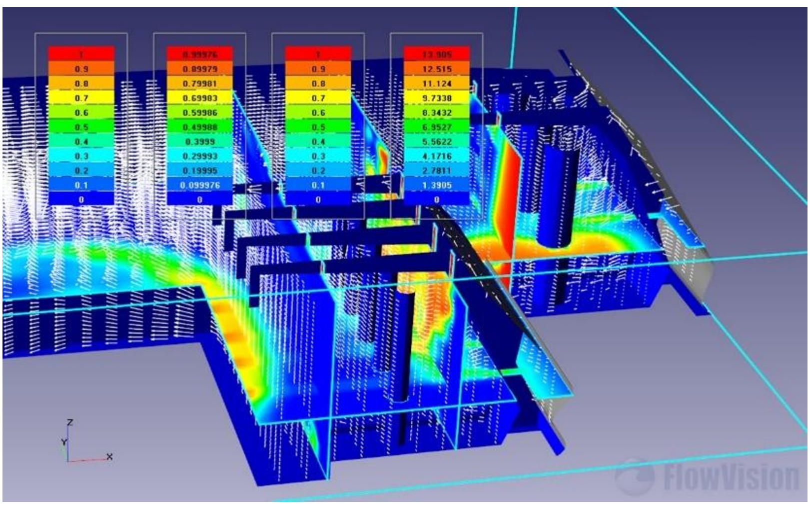

Fig. 2. Example of solving aerogasodynamics problems in FlowVision software package: Distribution of velocity vectors of outgoing and subliquefying jets influencing the formation of local accumulations ("lava" site).

In a general form, our proposed method of predicting the formation of FHEM accumulations in the working areas of coal mines, aimed at preventing occupational injuries of miners can be presented in the form of the algorithm of sequential actions of engineering and technical management personnel (ETMP) of a coal. At the same time, ETMP is understood both the mine director, directly giving orders, describing who does what and for what is responsible according to the algorithm, and responsible executors of each of the stages.

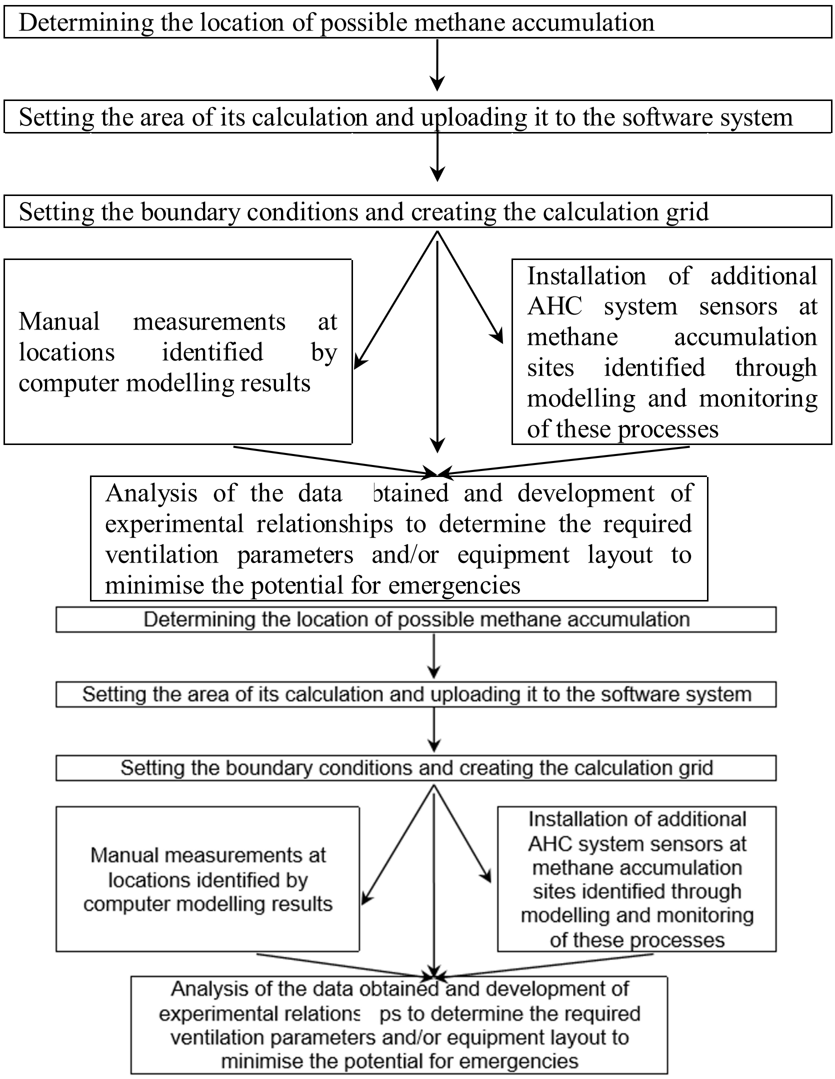

Fig. 3. Approximate algorithm of sequential actions of ETMP of a coal mine.

We believe that the application of the method of predicting the formation of FHEM accumulations in the space of mine workings, aimed both at the prevention of occupational injuries of miners, and the formation of FHEM in general will facilitate the task of specialists of aerological safety service to conduct targeted control of methane content in the workings of gas mines, as well as allow, scientifically justified, addressable, to install additional sensors of the aerogas control system.

4 Conclusion

The results of the comparative analysis of the results of modelling performed in the above described software packages have revealed good practical convergence of the obtained results when identical boundary and initial conditions are set at the input to the model. FlowVision and ANSYS Fluent software packages were chosen for further work.

We believe that computer modelling allows us to assess the feasibility of changing ventilation parameters in order to reduce the possibility of local and layer methane accumulations, as well as to determine the volume necessary to eliminate the danger in certain places. In addition, as our work in this direction continues, it will be possible to compile a catalogue (album of schemes) of characteristic locations of FHEM accumulations, which can be developed separately for each mine. Such an album of schemes, in which all the main most probable places of FHEM accumulation will be listed, will help to ensure industrial safety of coal mines, thus allowing to exclude incidents and accidents due to FHEM fires/explosions. In connection with the available material and technical capabilities and the results obtained, which are interesting in our opinion and are aimed at preserving human life, we consider it appropriate to continue work in this direction.

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