UDC [622.454:622.822.24]:622.8.1/.8.002.234 DOI: https://doi.org/10.15407/geotm2023.166.147

REDUCTION OF RISK OF CHOOSING THE OPTIMAL VENTILATION MODE FOR THE PERIOD OF ELIMINATION OF EXOGENOUS FIRE

Kokoulin I.Ye., Kliuiev E.S.

M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Science of Ukraine

Abstract. The time from the occurrence of an exogenous fire in a mine to its complete elimination can be conventionally divided into two periods: the operational time of the emergency elimination plan and the period of intensive fire extinguishing or fire cell isolation. In the first period, there is a significant number of working people in the mine, so the emergency ventilation mode must first of all ensure safe conditions for their evacuation. The issue of choosing an emergency ventilation mode in the mine ventilation network for use during the operational time of the emergency liquidation plan has been studied in sufficient detail. At the second stage of fire development, the ventilation mode should ensure the removal of combustion products by the shortest paths to the exit jet or to the workings where there are no people; to provide fresh air supply, normal temperature and minimal smoke in the areas where mining rescue works are carried out; reduce the intensity of fire development; to prevent overturning of ventilation jets in inclined workings. Among the listed requirements, there are both those that satisfy and those that contradict the criterion of the first period. Therefore, in a number of cases, during the liquidation of developed fires, it is necessary to change the ventilation mode to ensure the fulfillment of the considered conditions. A method of transition from the mode of the first period to the mode of the second is proposed, which consists in determining the list of ventilation modes that are subject to optimization. For each of them, workings are defined, in which it is possible to overturn the ventilation jet. Due to the minimization of their number, it is possible to prevent the spread of a fire zone gassed with gaseous products (that is, its minimization) and to complicate the conditions of conducting mine rescue operations. For this purpose, the theory of interrelationship of aerodynamic parameters of mine workings is used, which simplifies multi-fan ventilation calculations.

The described algorithm only seems somewhat cumbersome, since it is known from practice that in the area of action of intense thermal depression of the fire cell, several loosely connected workings cannot be located far from each other, with a possible spreading of the ventilation jet. Thus, by achieving the condition of non- spreading of the ventilation jet for one of the working, it is possible to indirectly solve the problem for a number of other workings, incidental to it, which significantly reduces the complexity of the calculation process.

Keywords: exogenous fire, emergency ventilation mode, thermal depression, interrelationship of aerodynamic parameters.

1. Introduction

The occurrence of an emergency with aerological consequences (exogenous or endogenous fire, sudden release of coal, rock or gas, explosion of methane or coal dust, etc.) requires the adoption of measures of ventilation influence on the mine ventilation network (MVN) in order to limit the zones of its gassing with gaseous products of the emergency, which, in its own right, in turn, simplifies the evacuation of people from emergency and dangerous areas of the coal mine. The implementation of these measures is connected with the emergence and necessity of minimizing risks of two types: emergency, related to the optimization of emergency evacuation and conducting mining rescue and restoration works, and aerological, which provides them. The latter consists in the organization of reducing the volume and quantitative characteristics of gassed zones.

Let's limit ourselves to considering one of the most common and complex types of underground emergencies - exogenous fires. The proposed technique, under some assumptions that simplify the formulation of the problem, can be applied when considering other emergencies with aerological consequences.

The time from the occurrence of an exogenous fire in a mine to its complete elimination can be conditionally divided into two periods: the operative time of the emergency liquidation plan (ELP; usually 1 hour is accepted from the moment the fire was detected) and the period of intensive fire extinguishing or fire cell isolation. In the future, during this period, additional mining rescue and restoration works are carried out.

In the first period, there is a significant number of working people in the mine, so first of all the emergency ventilation mode (EVM) must ensure safe conditions for their evacuation. The issue of choosing the EVM in the MVN for use during the operational time of the ELP has been studied in sufficient detail [1, etc.]; a generalized criterion for the effectiveness of the EVM has been developed, the analytical expression of which has the form [1]

$$\lambda = \sum \lambda(i,j) \left[exp \left(\frac{1}{\tau_{s.r.}} \cdot \sum_{(i',j') \in \mu(i,l)} \frac{C(i',j' \cdot L(i',j'))}{v(i',j')} \right) - 1 \right] \to \min_{M}, \qquad (1)$$

where $\lambda(i,j)$ is the capacity (mathematical expectation of the number of people [1]) in working (i,j), the direction of air movement in which is taken from node i to node j; $\tau_{s.r.}$ - time of the self-rescuer; $C(i',j')$ is the concentration of fire gases in the working (i',j'); $L(i',j')$ - the length of the working; $v(i',j')$ - the speed of movement of people through the working; $\mu(i,l)$ - the route of movement of people by works from node i to node l located on the surface; M is a set of ventilation modes from which the emergency mode is selected.

The transition from the mode used during the operational time of the ELP to the mode used after it is of interest, since the existing recommendations [2] are not sufficient for the development of an engineering methodology for calculating the numerical characteristics of the EVM.

At the second stage of fire development, the ventilation mode should ensure the removal of combustion products by the shortest paths to the exit jet or to the workings, where there are no people; to provide fresh air supply, normal temperature and minimal smoke in the areas where mining rescue works are carried out; reduce the intensity of fire development; to prevent overturning of ventilation jets in inclined workings.

Among the listed requirements there are both those that satisfy and those that contradict criterion (1). The first requirement is fulfilled, since the optimality of the criterion implies the minimum number of gassed workings in which people are located. The second requirement may not be satisfied, since it is often necessary to successfully extinguish a fire after the complete evacuation of people from the emergency area, to reverse the ventilation jet in it and to carry out mining rescue and restoration work from the side of a new fresh jet. The third requirement is in clear contradiction with the criterion, since the intensity of fire development (or, which is practically the same, the speed of movement of the fire center) is directly proportional to the speed of the air jet in the workings (i,j) of zone θ, gassed with combustion products. Its decrease leads to an increase in $C(i,j)$ and, thereby, to a deterioration of the criterion values. The fourth requirement is ambiguously satisfied, since the thermal depression in inclined workings depends on the temperature in the fire center, which, in turn, depends on the duration of fire development. As a result, the EVM, used during the operational time of the ELP, may later turn out to be ineffective, contributing to, rather than preventing, the overturning of the jet in inclined and vertical workings. Therefore, in a number of cases, during the liquidation of developed fires, it is necessary to change the ventilation mode to ensure the fulfillment of the considered conditions (the first condition after the end of the operational time of the ELP is omitted).

The purpose of the article is to substantiate the methodology for choosing an emergency ventilation mode for the period of liquidation of an exogenous fire (after the end of the operative time of the plan for liquidation of emergencies), and the task of the article is a brief description of the developed method and algorithm.

2. Methods, results and discussion

The method of selecting the EVM for use during the period of fire suppression is based, as well as during the operational time of the ELP, on determining the list of ventilation modes, the implementation of which is possible at the stage under consideration, and comparing them according to the degree of satisfaction of the listed conditions.

1. The set of workings $\theta_{v.s.}$ is determined, in which overturning of the ventilation jet $\theta_{v.s.} = \{(i, j), Hj < Hi\}$(violation of stability) can occur, where H_i is the height mark of node *i*. and the direction of air movement, as before - from *i* to *j*.

2. For the selected ventilation mode, the natural air distribution is calculated and the amount of air $Q(i,j)$, $(i,j) \in \theta_{v.s.}$ is determined.

3. Thermal depression is determined

$$H^{\tau}_{\upsilon(i,j)} = \sum_{(i,j)\in v(i,j)} H^{\tau}(i',j),$$

where $v(i,j)$ is the cycle of the ventilation network, in which the value of thermal depression is calculated.

The value of $H^{\tau}(i',j')$ can be calculated by any known method, for example

$$H^{\tau}(i',j') = -365(H_i - H_j)\frac{t_i + t_j - 40}{(t_i + t_j + 546)\cdot 293},$$

where t_i is the air temperature at node i;

$$\{H_i\}\{\ \} = \{\{H_i\}\{\ \}, signQ(i,j) = signQ(i'',j'')\rfloor;$$ (i'', j'') is the base of $v(i, j)$.

If $H^{\tau}_{\upsilon(i,j)} < R((i,j)Q^2(i,j)$ – no additional calculations are required, since the jet in *(i,j)* is stable under this regime, and the next $(i,j)=\theta_{v.s.}$ is considered.

4. If $H^{\tau}_{\upsilon(i,j)} > R((i,j)Q^2(i,j)$ – is determined by amount of air $Q'(i,j)=\left(H^{\tau}_{\upsilon(i,j)}/R(i,j)\right)^{1/2}$, i.e. air flow in working *(i, j)*, at which the overturning of the ventilation jet occurs in it. In order to satisfy the condition of no overturning, it is necessary to ensure in *(i, j)* the air flow $Q''(i,j)=Q'(i,j)+Q'(i,j)$, where *Q'(i, j)* is determined for practical reasons in order to exclude jet overturning in *(i,j)* due to calculation $H^{\tau}_{\upsilon(i,j)}$ errors.

To find *Q''(i, j)*, the theory of interconnection can be used, which describes the interaction between the flows in workings *(i, j)* and *(i', j')* a linear equation of the form [3]

$$Q(i,j)=Q^0(i,j)+k^{(i',j')}_{(i,j)}\left[Q(i',j')-Q^0(i',j')\right], \qquad (2)$$

where the index "0" indicates the amount of air in the working at a certain basic state of air distribution in the MVN; $k^{(i',j')}_{(i,j)}$ - the coefficient of interconnectedness, characterizing the change in *Q(i, j)* when *Q(i', j')* changes.

If we calculate all $(i,j) \in \theta_{v.s}$, (i',j') N_v, where N_v is the set of main fan units (MF), according to the methodology given in [3], it can be noted that the calculation is sufficient accuracy of 0.01, i.e., if $k^{(i',j')}_{(i,j)} < 0.01$ should be taken as $k^{(i',j')}_{(i,j)} = 0$, which indicates a weak interconnectedness between the sections of MVN and will contribute to a significant simplification of calculations in the future.

The complex interconnectedness of air consumption in workings $(i',j') \in N_v$ and air consumption in *(i, j)* is described by the equation

$$Q(i,j)=Q^0(i,j)+\sum_{(i',j')\in N_v} k^{(i',j')}_{(i,j)}\left[Q(i',j')-Q^0(i',j')\right], \qquad (3)$$

where $Q(i',j')-Q^0(i',j')=\Delta Q(i',j')$ is the increase in air consumption at the main fan. Value *Q(i', j')* are determined from the system of equations

$$\sum_{((i',j')\in N_v)} v^{(i',j')}_{(i'',j'')}\Delta Q(i',j') = Q(i'',j'')Q^0(i'',j''), \qquad (4)$$

where

$$v_{(i'',j'')}^{(i',j')} = \begin{cases} -\Delta Q(i'',j'')k\dfrac{(i'',j'')}{(i',j')},(i',j') \neq (i'',j'') \\ Q^0(i'',j''),(i',j') \neq (i'',j'') \end{cases}$$

$$\Delta Q(i'',j'') = Q^0(i'',j'') - Q(i'',j'').$$

Substituting into the system of equations (3)-(4) instead of *Q(i,j) Q(i'',j'')*, we will obtain the value *Q(i',j')* from it, which provides air flow *Q(i'',j'')* in the working under consideration. It is necessary to check whether the required *Q(i',j')* falls within the working area of the fan installed at *(i',j')*. If this condition is satisfied for all $(i',j') \in N_v$, then the solution for *(i,j)* is obtained.

5. Equations similar to (3)-(4) are constructed taking into account that *(i',j')* is taken from *(i,j)*. item p.4, and as *(i,j)* all remaining $(i,j) \in \theta_{v.s}$. If $Q(i,j) \geq Q(i'',j'')$, which is determined from them for all $(i,j) \in \theta_{v.s}$, then the solution is obtained.

6. If there exists *(i,j),* $Q(i,j) < Q(i'',j'')$, then calculations for it are carried out similarly to item 4. It is only necessary to choose *Q(i,j)* at each step in such a way that the situation $Q(i,j) < Q(i'',j'')$ does not arise in any of the previously considered $(i,j) \in N_v$.

7. If all the performed actions do not remove the main fans from the working areas, then the mode under investigation satisfies the condition of no overturning and can be considered optimal for use in emergency conditions. The following mode is selected, which satisfies all conditions and at the same time is the one that is most easily implemented in emergency conditions. For example, all other things being equal, the normal ventilation mode that existed in the mine before the emergency is optimal, since its implementation will not require ventilation maneuvers.

8. If none of the modes was found that would ensure the condition of non-overturning of the ventilation jet, then the one that ensures the best fulfillment of the other conditions is selected as the emergency mode.

The use of the described method will be more reliable if, as the initial temperature in the center of the fire, you choose not the value *t(i,j)*, which depends on the time of fire development, but t_{max} – the temperature under the condition $t = \infty$, since it is impossible to predict in advance the duration of liquidation works emergencies. The value depression $H_{\upsilon(i,j)}^{\tau}$ calculated taking into account t_{max} will obviously be the maximum possible, which guarantees the correct choice of *Q(i'',j'')* at any time of fire elimination.

3. Conclusions

The described algorithm only seems somewhat cumbersome, since it is known from practice that in the area of intense thermal depression of a fire centre, several weakly connected and distant workings $(i,j) \in \theta_{v.s}$. Not overturning the ventilation jet for one of them, it is possible to indirectly solve the problem for a number of others, incidental to it, which significantly reduces the complexity of the calculation process.

Thus, it can be concluded that the risk of implementing an incorrectly selected emergency ventilation mode lies in the possibility of incorrectly determining the reaction of some $(i,j) \in \theta_{v.s}$ to its ventilation effect. Due to this, the zone of gassing of the MVN with gaseous fire products may change unexpectedly (in the direction of increase), which will complicate the conduct of mining rescue and restoration work. Therefore, the implementation of the proposed method of reducing the negative impact of this factor can be considered useful.

REFERENCES

1. Potemkin V.Ya., Kozlov Ye.A., and Kokoulin, I.Ye. (1991), "*Avtomatizatsiya sostavleniya operativnoy chasti planov likvidatsii avariy na shakhtakh i rudnikakh*" [Automation of the preparation of the operational part of plans for the elimination of accidents at mines and mines], Technyka, Kyiv.

2. Ministry of Coal Industry of Ukraine (2010), *NPAOP 10.0-1.01-10 Pravyla bezpeky u vugilnykh shakhtakh* [NLASL 10.0-1.01-10 Rules of safety in coal mines], Osnova, Kiev, UA.

3. Potemkin V.Ya., Saponchyk S.V. and Sapunova, I.O. (1980), "An approximate method of calculating air distribution in a ventilation network", *Technics of safety, labor protection and mining rescue work: Scientific and technical work. Ref. Sat. TsNIEIUgo*l. no. 8, p. 5–7.

About the authors

Kokoulin Ivan Yevhenovych, Candidate of Technical Sciences (Ph.D.), Senior Researcher, Senior Researcher in Department of Problems of Underground Mining at Great Depths, M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM of the NAS of Ukraine), Dnipro, Ukraine, kokoulin52@ukr.net

Kliuiev Eduard Serhiiovych, Candidate of Technical Sciences (Ph.D.), Senior Researcher, Senior Researcher in Department of Problems of Underground Mining at Great Depths, M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM of the NAS of Ukraine), Dnipro, Ukraine, eduard.igtmnanu@gmail.com

ЗНИЖЕННЯ РИЗИКУ ВИБОРУ ОПТИМАЛЬНОГО ВЕНТИЛЯЦІЙНОГО РЕЖИМУ НА ПЕРІОД ЛІКВІДАЦІЇ ЕКЗОГЕННОЇ ПОЖЕЖІ

Кокоулін І.Є., Клюєв Е.С.

Анотація. Час від моменту виникнення у шахті екзогенної пожежі до її повної ліквідації може бути умовно поділений на два періоди: оперативний час плану ліквідації аварії і період інтенсивного ведення робіт з гасіння пожежі або ізоляції пожежного осередку. У перший період у шахті знаходиться значна кількість працюючих людей, тому аварійний вентиляційний режим повинен у першу чергу забезпечити безпечні умови їх евакуації. Питання вибору аварійного вентиляційного режиму у шахтній вентиляційній мережі для використання протягом оперативного часу плану ліквідації аварій вивченні достатньо докладно. На другому етапі розвитку пожежі вентиляційний режим повинен забезпечувати відведення продуктів горіння найкоротшими шляхами до вихідного струменю або до виробок, у яких відсутні люди; забезпечувати подачу свіжого повітря, нормальну температуру і мінімальну задимленість на ділянках, де проводяться гірничорятувальні роботи; знижувати інтенсивність розвитку пожежі; попереджувати перекидання вентиляційних струменів у похилих виробках. Серед перерахованих вимог є як такі, що задовольняють, так і такі, що суперечать критерію першого періоду. Тому у ряді випадків при ліквідації розвинених пожеж доводиться змінювати вентиляційний режим для забезпечення виконання розглянутих умов. Запропоновано метод переходу від режиму першого періоду до режиму другого, який полягає у визначенні переліку вентиляційних режимів, які підлягають оптимізації,. Для кожного з них визначаються виробки, у яких можливе перекидання вентиляційного струменю. За рахунок мінімізації їх кількості досягається недопущення поширення загазованої газоподібними продуктами пожежі зони (тобто її мінімізація) і ускладнення умов ведення гірничорятувальних робіт. З цією метою використовується теорія взаємопов'язаності аеродинамічних параметрів гірничих виробок, що спрощує багатовентиляторні розрахунки вентиляції.

Ключові слова: екзогенна пожежа, аварійний вентиляційний режим, теплова депресія, взаємопов'язаність аеродинамічних параметрів.