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THE RISK REDUCING OF MINERS EVACUATION IN CASE OF AN ACCIDENT WITH AEROLOGICAL IMPACT

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Abstract. Displacement of miners along emergency escape routes involves various types of risk. First of all, displacement of miners occurs rapidly in order to have time gap to carry out the evacuation within the operational time according to the emergency recovery plan. Further, the evacuation is carried out along routes that arranged far worse compared to that ones for the displacement of miners to their workplaces as well as escape routes provided with emergency ways. Further, strict compliance with regulations of the Safety Regulations for displacement along the gassy area of the route until reaching the nearest fresh stream and, after that, displacement exclusively along the clean stream, in some cases significantly increases the route length. For example, in case, when switching points as duplicate self-rescuers could be used, the exit during the operational time of the emergency recovery plan could be unreachable, while organizing of the second switching point is prohibited by the Safety Regulations, etc. In addition, the risk of emergency evacuation is due to the fact that, unlike classical route tasks, routes are built not “from point to point”, but from the initial set (the position of the emergency recovery plan) to the final one (the set of exits to the surface of mine shafts involved for evacuation). The individual risk differs for certain groups of miners evacuated from the workings according to the position of emergency recovery plan. Therefore, the study is devoted to the elaboration of a method reducing the risk of emergency evacuation with a probable (within acceptable limits) violation of the requirements of the Safety Regulations as well as correcting these regulations.

Strict compliance with regulations of the Safety Regulations is able to complicate the emergency evacuation process. In modern mines provided with long and complicated ventilation networks, due to an exogenous fire outbreak, large gassy areas could be formed, which are, able to cause complications during emergency evacuation. Bypassing these areas means increasing the evacuation time that could lead to the exceeding of operational time according to the emergency recovery plan.

An algorithm for correction of escape routes is proposed, which, provided that real information about possible escape routes is obtained by means of an emergency simulation, will make it possible to shorten these routes, although they contain clean and gassy areas alternately. The algorithm is recommended for the discussion purpose in order to correct some regulations of the Safety Regulations.

Keywords: emergency recovery plan, mine ventilation network, gassy area, emergency escape routes.

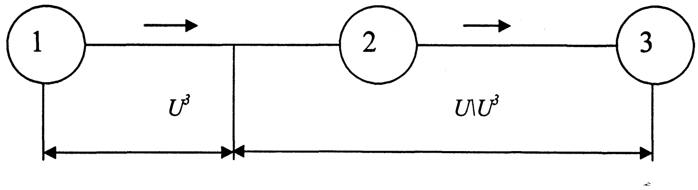
1. Introduction

The main task of people who are at their workplace in the mine, after receiving an alarm signal, is to get out of the dangerous area of the mine ventilation network (MVN), where they are located. Further they should be displaced to the safe areas and finally they have to reach out mine shafts for emergency evacuation. Thus, it is assumed that the route is well-known to the miners. For normal operating conditions in the mine emergency escape routes is the main route to the workplace. But it is more complicated for emergency conditions.

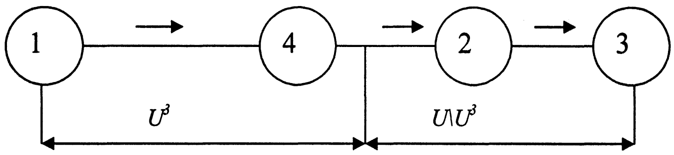
Emergency escape route may not coincide not only with the main route, but also with emergency exits, which must be provided for emergency reversible ventilation mode or some processing violations that do not allow to use the main route as a conventional one. There is a problem of preliminary selection for the system of escape routes as well as their embedding in the emergency recovery plan (ERP) emerges [1, 2] during its elaboration, along with a problem of miners awareness of the emergency recovery plan.

Analysis of the topological structure for MVN and the features of the exogenous fire impacts, carried out by a number of researchers in order to assess the impact of

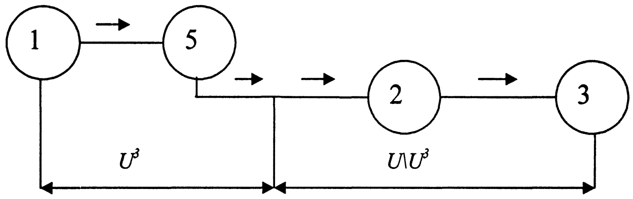
MVN gassy areas at the designing stage of emergency shutdown system, allows to develop a route structure for all possible evacuation conditions (Fig. 1).



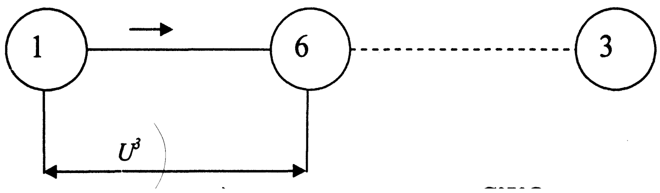
a) conventional route from the starting point to the surface



b) the route containing switching point to the duplicate self-rescuers (SPSR)



c) the route containing other vertical or inclined sections



d) route to back-pack life-support chamber (BPLS chamber)

1 - starting point of emergency evacuation; 2 - starting point of the shaft, which is part of the emergency escape route; 3 - end point of the route (located on the surface of the mine); 4 - location of the SPSR; 5 - starting point of the intermediate vertical section of the route; 6 - location of the BPLS chamber

Figure 1 – Overall structure of the emergency escape route:

The following nomenclature has been used in Figure 1: U, $U^з$ - sets of all and gassy areas of the MVN respectively; SPSR - switching point to the duplicate self-rescuers [3,4]; BPLS - back-pack life-support chamber in case of emergency alerts [5] (there are several types of this chamber with different names).

Figure 1 shows that the emergency escape route could be divided into ergonomically different areas as follows:

a) section 1-2 - operates as an independent section, which workings partially pertains to $U^з$ and $U \setminus U^з$;

b) section 2-3 – the workings of the mine shaft, all the workings of this section pertain to $U \setminus U^з$;

c) section 1-4 - operates as an independent section, if all $(i, j) \in U^з$ as well as $\tau_{1\text{-}4} = \tau_{rr}$;

d) section 1-5 reaches a vertical workings, while point 5 (see Figure 1) may either pertain or not to $U^з$;

e) section 1-6 is a set of workings of the emergency escape route from point 1 to the BPLS chamber (see Figure 1); all its $(i, j) \in U^з$, and the route does not reaches the surface.

Thus, the purpose is to make up several types of routes: the main route, the common one, the route from the definite emergency area of the working to the mine shaft that is able to operate as emergency escape route and further to the surface (in case if $\tau_{\mu(i,j)} \in \tau_{rr}$, where $\tau_{\mu(i,j)}$ - time required to cover a distance of the route μ) from point i to point j, where τ_{rr} – operating time for the selected type of self-rescuer as well as auxiliary one:

a) if $\tau_{\mu(i,j)} \in \tau_{rr}$ then it is route #1, which is part of the main route to the SPSR, and route #2 from the SPSR to the surface;

b) if it is impossible to form such a route or organize the SPSR on the main route then the route #3 leads not to the surface, but to the BPLS chamber designed for awaiting rescue squads of the State Paramilitary Mine Rescue Service (SPMRS) that takes additional measures in order to continue emergency evacuation process.

2.Methods

Evacuation routes are associated with different types of risk. First of all, the miners' displacement must be quite swift in order to carry out the evacuation within the operational time according to the emergency recovery plan. Further, the routes involved for evacuation process are arranged far worse compared to that ones for the displacement of miners to their workplaces as well as escape routes provided with emergency exits. Further, Further, strict compliance with regulations of the Safety Regulations for displacement along the gassy area of the route until reaching the nearest fresh stream and, after that, displacement exclusively along the clean stream, in some cases significantly increases the route length and forces to use options b) and d), i.e. more difficult and dangerous ones. It could happen that the use of SPSR does not allow to leave dangerous area within the operational time according to the emergency recovery plan while an arrangement of the alternate route is prohibited by [1], etc. In addition, the risk of emergency evacuation is associated, unlike the conventional route tasks, with routes arrangement not from starting point to the destination point, but from the initial set (ERP position) [1,6] to the final set, i.e. set of ways to the surface through the mine shafts). The individual risk differs for certain groups of miners evacuated from the workings of the ERP position.

Therefore, research objective is elaboration of a method for reducing the risk of emergency evacuation process with possible (within acceptable limits) violation of the requirements [1] as well as correction of these requirements.

Let's define a set of workings (i_k, j_k) of a dangerous area $П$ miners have to be evacuated from as follows

$$\Pi: \{(i_k, j_k), \exists (i_k, j_k) \in U^3$$

Emergency escape route $\mu(i,j)$ for miners:

$$\mu(i,j)=\sum_{k=1}^{n}(i_k, j_k), j\in M, i_1=i, j_n=j, j_k=i_{k+1},$$

where M is the set of MVN nodes located on the surface of the mine.

If the position of the ERP is selected in accordance with the requirements [1], then for any of the working branches (i_k, j_k) and (i_p, j_p) the following condition must hold

$$\mu(i_k,j) \equiv \mu(i_p,j), j \in M \quad (1)$$

The operative part of the ERP in this case should include the phrase: "Miners in the workings < list of workings' names $(i_k, j_k) \epsilon \Pi$ >, should follow the route <list of workings' names $(i_k, j_k) \epsilon \mu (i_k, j), (i_k, j_k)) \epsilon U^3$ > as well as follow the route "name of the route (i_l, j) > to provide their ascent to the surface of the mine". However, in practice this is not always possible. Condition (1), as a rule, is not satisfied, so the most efficient estimation is that one by means of human capacity parameter, where $\lambda (i_k, j_k)$ is a expected value of the number of people in (i_k, j_k) at the time of evacuation as well as formation of $\mu (i_{k'}, j), j \epsilon M$ on condition that $\lambda (i_k, j_{k'}) = \max \lambda (i_k, j_k), (i_k, j_k) \epsilon \Pi$. It provides the evacuation of the largest group of miners from $(i_k, j_k) \epsilon \Pi$, and implies that other people, starting from a certain place, follow the same route. The above verbal description of the route is getting, however, incorrect; certain groups of people may be ordered to follow a route whose initial branch $(i_{k'}, j_{k'})$ is located far from their starting point (i_p, j_p).Their emergency escape route $\mu (i_p, i_{k'})$ to this initial branch is uncertain. If in addition $\exists (i_k, j_k) \epsilon \mu (i_p, i_{k'}), (i_k, j_k) \epsilon U^3$ this is a gross violation of the requirements of paragraph 3.6 [1], thus $\mu (i_{k'}, j)$ for mining workings $(i_k, j_k) \in \Pi$ should be considered as incorrect.

This issue could be resolved in such a way: since the positions of the PLE are chosen so that $\forall (i_k, j_k) \in \Pi$ are passable for miners, where Π is a finite connected graph selected on condition of passability as well as a tree Π_0 constructing, which vertices i_l values could be assigned as follows

$$\lambda_{i_p} = \sum_{(j_m, i_l) \in \Pi} \lambda(j_m, i_l) \quad (2)$$

As a result of such a transformation, emergency escape route will be laid out not from an arbitrary set Π, but from an ordered tree-like structure, yet the branches pertaining to Π_0 are emergency escape routes. By assigning these branches values P_k that describe the difficulty of their covering (length, gas levels, haze level, height, inclination degree, etc;), the point $i \epsilon \Pi$ could be determined, which, with the minimum values of parameters ΣP_k for the routes $\mu (i_k, i')$ miners are able to reach so that ΣP_k

for $\mu (i', j)$ takes its minimum value. Looking up for such a point could be implemented by means of the following algorithm:

a) $i_k \in M_0$ should be determined, where M_0 is the set of "hanging" nodes of the tree Π_0;

b) i_k ' should be determined on condition $\lambda^{0}_{i'_k} = max\, \lambda^{0}_{i_k}$ (index 0 indicates the initial distribution of indicators λ_{i_k});

c) all the values $i_k \neq i_k'$ are excluded from consideration, while for all nodes $j_m \in (i_k, j_m)$ the following operation is performed:

$$\lambda^{1}_{j_m} = \lambda^{0}_{j_m} + \sum \lambda_{i_k} .$$

Thus, the transition to the tree Π_1 is provided, which is obtained from the tree Π_0 by neglecting all $i_k \in M_0$, except one that has the maximum value of the indicator (2). It is clear that as a result of such an operation M_0 becomes a new set M_1, where other nodes become "hanging" ones;

d) operations a), b) and c) are repeated until either $M_n = \{i_p\}$, i.e. it becomes one isolated node, or $M_n = \{i_p, i_l\}$, where $\lambda^{n}_{i_p} = \lambda^{n}_{i_l}$. For the first case, the desired point $i' = i_p$, for the second case point i' is placed within the branch connecting i_p and i_l.

Emergency escape route from Π could be written as follows: "Miners in the workings < list of workings' names $(i_k, j_k) \in \Pi$ >, should get to < name of (i_p, j_l) >, then they should follow the route <list of workings' names $(i_k, j_k) \in \mu (i', j), (i_k, j_k) \in U^{з}$ > as well as follow the route < name (i_l, j) > to provide their ascent to the surface of the mine".

In realistic situation with respect to the values of $\lambda (i_k, j_k)$ for $(i_k, j_k) \in \Pi$ their exact value are unknown. It could be expressed as follows

$$\lambda_{min}(i_k,j_k) \leq \lambda(i_k,j_k) \leq \lambda_{max}(i_k,j_k), \qquad (3)$$

because the very concept of expected values implies the possibility of an error emergence. The error value for this case could be significant due to

$$\lambda_{min}(i_k,j_k)=0$$

$$\lambda_{max}(i_k,j_k) = \Sigma\, \lambda(i_k,j_k),\ (i_k,j_k) \in \Pi$$

Therefore, it is impossible to find the exact solution of the problem in the general case, i.e. a single point i' could not always be found. A minimum frame of the tree should be mentioned, that consists of the list of workings, which every point is an analog of i' in the problem described above. Then the formation of the emergency escape route from the workings $(i_k, j_k) \in \Pi$ to the node j is reduced to determining the minimum frame of the tree $\mu (i', j'), j' \in M_0$ and the description of the route $\mu (i',j') \subset \mu (i', j)$.

Let i' (see above-mentioned case) is a solution of the problem under the condition

$\lambda_{min}(i_k, j_k) = \lambda(i_k, j_k) = \lambda_{max}(i_k, j_k)$, while $i_p \epsilon M_0, p = 1,2,...$ It could be shown that if values $\forall \lambda_{i_k} \Rightarrow max, i_k \in \mu(i',i_p), i_k \neq i'$ and λ_{i_k} = const for $\forall\ i_k \notin \mu(i',i_p)$, then the set of solutions of the problem for considered and satisfied condition (3) represent the route $\mu(i',\bar{i})$, where $\mu\ (i',\ i_p)$ and represents the solution of the problem for the values $max\, \lambda_{i_k}, i_k \in \mu(i',i_p)$ Otherwise, if the values for all $\lambda_{i_k} \Rightarrow min, \lambda_{i'} \Rightarrow min, i_k \in \mu(i',i_l), l \neq p$, i $\lambda_{i_k} = const, i_k \in \mu(i',i_p)$, then the set of solutions of the problem is a route $\mu\ (i',i)$, where i $\lambda_{i_k} \Rightarrow min,\ \lambda_{i'} \Rightarrow min,\ i_k \in \mu(i',i_l),\ l \neq p$, i $\lambda_{i_k} = const,\ i_k \in \mu(i',i_p)$, and represents the solution of the problem for the values $min\ \lambda_{i_k},\ i_k \in \mu(i',i_l),\ l \neq p$.

Taking into account above-mentioned statements, the algorithm for solving the problem for $\lambda\ (i_k, j_k)$, which satisfies condition (3), is as follows:

a) for $min\ \lambda\ (i_k,\ j_k),\ (i_k,\ j_k) \in \Pi$, value for i_0', should be determined (similar to determining i' in above-mentioned problem);

b) $\forall\ \lambda_{i_k}$ are replaced by $max\, \lambda_{i_k}$, $i_k \in \mu(i',i_1),\ i_1 \in M_0$,, i_1' should be determined similar to i_{r_2}', if - $i_1' \equiv i_0'$ the route $\mu\ (i',\ i_2),\ i_2 \in M_0$ should be considered, etc.;

c) if $i_1' \neq i_0'$ - $\forall\ \lambda_{i_k}$ are replaced by min λ_{i_k}, while λ_{i_1}' are replaced by $min\, \lambda_{i_1}'$, $i_k \in \mu(i_0',i_1'),\ i_2'$ should be determined. If $i_2' \equiv i_1'$ the route $\mu(i',i_2),\ i_2 \in M_0$ should be considered, etc.;

d) after r-times reiterations of the procedures according to a)-c) a point i_{r_1}' should be determined, while all the points $\mu(i_0',i_r')$ are the solution of the problem for $\mu(i',i_1)$, etc.;

e) reiteration of the actions of according to a)-d) for $\forall\ i_p,\ i_p \in M_0,\ p=1,2,...,n,$ the following expressions could be obtained

$$\mu = i_0' \cup \mu(i_0',\ i_{r_1}') \cup \mu(i_0',\ i_{r_2}') \cup \ldots \mu(i_0',i_{r\,n}')$$

- the optimum frame of the tree Π_0. Emergency evacuation route from the workings Π could be written as follows: "Miners located in the workings <list of workings' names $(i_k,j_k) \in \Pi$ >, should follow the route < list of workings' names $(i_k,j_k) \in \mu \cup \mu(i,j)$, $(i_k,j_k) \in U^3$,, where i □ M_0 is the root of the tree Π_0 > as well as follow the route < name (i_l, j) > to provide their ascent to the surface of the mine".

Two features should be noted that may arise during the practical implementation of the algorithm:

a) since the real position of the ERP could reach a significant length, μ is not a route in the strict sense of the word, thus it could be a tree-like structure itself. In this case, a versatile description of the route using μ, mentioned above, is incorrect, because the list of branches $\mu\ (i',\ j)$ includes branches that are not included in the route sequentially. In this case, the problem should be solved for μ under the condition

λ_{i_k} *=const,* $i_k \in \mu$. The point *i''* should be determined, relative to which can construct a strict route μ *(i'', j)* could be constructed. However, the mathematical strictness of the algorithm is somewhat violated, because, in fact, $i_k \in \mu$ satisfies condition (3);

b) in practice there are positions *П*, from which the evacuation of miners could be provided not through a single, but several boundary points $i_k \in M_0$. Despite the fact that such a position was selected with an obvious violation of the requirements [1], this algorithm allows to form a single optimum route from the workings. In order to provide it, let's choose *min* $\mu(i_k, j_p)$, $\forall j_p \in M$ (that allows to choose *j*) and construct a tree $П_0$ so that its root is located at the point $i'_k \in \mu(i'_k, j) = min\ \mu(i_k, j_p)$. In this case, taking into account the above-mentioned assumption that the displacement starts from the nodes of the set M_0 to the root of the tree, the solution of the problem is similar to the above-mentioned one.

Taking into account the requirements [1] for the evacuation process of the miners through the workings with fresh air and, if this kind of evacuation is not possible, evacuation through the workings with a minimum gassy area, makes to identify workings pertaining to the gassy area and designate them in some way in order to artificially bypass them and not to include them in the route being constructed. Thus, in [7] it is proposed to artificially extend gassy workings; which overall passability could calculated as follows

$$P(i,j)=L(i,j)[1+K|cos\ \alpha|+K_1], \tag{4}$$

where *L (i, j)* - real length of the working, determined by means of geometry;

$$cos\ \alpha=\frac{H_j - H_i}{L(i,j)},$$

K - coefficient that takes into account the direction of the miners' displacement within the inclined working; K_1 - parameter that describes the passability of working *(i, j)* by means of haze level estimation. If $U^\tau \neq \varnothing$, then parameter K_1 should be added to expression (4).

This approach allows to obtain the solution for the problem of dividing the set of workings into categories according to the passability degree. In fact, if $cos\ \alpha = 0$ as well as $K_1 = 0$ the working is horizontal and passable for miners, while $P(i, j) = L(i, j)$ is its length. Time needed to cover the distance within the working could be calculated as follows: $t(i, j) = L(i, j) / V$, where *V* is the velocity of miners' displacement within the horizontal working for normal conditions (3 km / h).

If cos $\alpha \neq 0$ is the inclined working and *L (i, j)* is artificially extended by the value of $L(i, j)\ K\ |\ cos\ \alpha\ |$. The value of the coefficient *k* could be calculated based on the reduction of the miners' displacement velocity depending on the angle of inclination of the route within the working; then *t (i, j)* has a real physical meaning in this case as well.

The parameter $K_1 \neq 0$ regulates the degree of passability for workings by means of haze level estimation. However, [1] and other regulatory documents do not control this indicator. If the concentration value of gases equals $C(i, j) \neq 0$ then working is unfit to be involved in evacuation route. Therefore, the following feature should be stated as a restriction: if the working on the basis of the haze level value is impassable for miners ($C(i, j) > C_{max}$ is the concentration for which the protective performance of the self-rescuer is not ensured) then K_1 takes the value $K_1=\infty$. Otherwise - K_1 is determined by practical reasons. Moreover, the above-mentioned approach has an important consequence: despite the fact for $K_1 = \infty$, the working is considered as impassable for miners on the basis of emergency parameters, it is not excluded from the list of branches from which the emergency escape route could be formed, it's just the least preferred option. At least, in the absence of other routes to rescue the miners, this working could be involved. This is confirmed in practice, when miners were cut off from the planned exit from emergency area, the ERP often includes the sentence as follows: "Miners…, bypassing the fire, move…", i.e. in an extremely dangerous situation when the miners' lives may depend on it, miners are allowed to move through the working of the MVN, where $C(i, j) > C_{max}$.

Thus, the use of concept of artificial extension of workings unfit for their inclusion in the emergency escape routes causes, when approaching the gassy area of MVN, an attempt to bypass this area, even (if the value of K_1 is selected incorrectly) at the cost of significant overestimating of ergonomic parameters of the route. This approach cannot be considered as efficient one; often the coverage of a small gassy area of the route significantly reduces the overall evacuation time without reducing its safety. However, this approach is not widely accepted; referring to the uncertainty of information about the dynamics of MVN gassy areas, most ERP compilers prefer to significantly extend the route through the workings with fresh air without risking the use of the gassy ones. However, increasing the reliability of forecasting of the mine's haze level by means of simulation allows to raise the question of the necessity to study the ratio of areas with fresh air and gassy areas of the emergency evacuation route in the process of its optimization.

3. Results and discussion

Let's consider the structure of the next step of optimization in more detail, specifically, the search, after passing (i, j), for the next working to be included in the route under construction. The following cases might be considered:

a) $C(i, j) = 0$, and $\forall (i_k,j) \Rightarrow C(i_k,j) = 0, \forall (j,j_k) \Rightarrow C(j,j_k)=0, i_k \neq i$.. The displacement takes place in the area with fresh air, the direction of displacement is determined exceptionally by the following geometric, and hence ergonomic, parameters: the ratios $L(i_k,j_k), H_{i_k}, H_{j_k}$, for all the workings, incidented to the node j;

b) $C(i, j) = 0$, and $\exists (i_1,j) \Rightarrow C(i_1,j) = 0, (i_2,j) \Rightarrow C(i_2,j) \neq 0, (j,i_3) \Rightarrow C(j,i_3) \neq 0$. In other words, node j is located at the border of gassy area; for workings incidented to this node values for $P(i_k,j_k)$ could be calculated as follows

$$P(i_1,j)=L(i_1,j)[1+K|\cos\alpha|]$$

$$P(i_2,j)=L(i_2,j)[1+K|\cos\alpha|+K_1']$$

$$P(j,i_3)=L(j,i_3)[1+K|\cos\alpha|+K_1''],$$

where K_1', K_1'' - parameters that describe the necessity to overcome the boundary of the gassy area and area with fresh air of the MVN. $K_1' \neq K_1''$, although both workings (i_2, j) and (j, i_3) are hazed ones. This is explained by the fact that further displacement of miners down the route (j, i_3) takes place in cocurrent flow of the ventilation jet, while for the route (i_2, j) displacement of workers takes place in countercurrent flow of the ventilation jet, which is not strictly prohibited [1]. But in practice it is not usually recommended because miners could be caught in a fire. Therefore $K_1'' < K_1'$; a reasonable choice of their practical values will require additional research for each mine;

c) $C(i,j) \neq 0$, i $\forall (i_k,j) \Rightarrow C(i_k,j) \neq 0$, $\forall (j,j_k) \Rightarrow C(j,j_k) \neq 0$, $i_k \neq i$. The displacement takes place within a gassy area; since the danger build up due to inclusion of the next gassy working in the emergency escape route barely depends on its length linearly (unless, of course, the limitation on the term of protective performance of the self-rescuer has not been violated). Thus, determining $P(i_k, j_k)$ for (j, j_k) allows neglecting parameter K_1''. During consideration (i_k, j) it is necessary to accept $K_1' \neq 0$;

d) $C(i,j) \neq 0$, and $\exists (i_1,j) \Rightarrow C(i_1,j)=0$, or $\exists (j,i_2) \Rightarrow C(j,i_2)=0$. Further displacement of the miners down this route, of course, is prefferable, because it indicates leaving the gassy area. Therefore, for the workings incidented to the node j,

$$P(i_1,j)=L(i_1,j)[1+K|\cos\alpha|]$$

$$P(j,i_2)=L(j,i_2)[1+K|\cos\alpha|]$$

$$C(i_k,j)\neq 0 \Rightarrow P(i_k,j)=L(i_k,j)[1+K|\cos\alpha|+K_1],$$

i.e., for hazed workings adjacent to the nodes of the boundary of the hazed zone, the calculation must be performed taking into account the parameters K_1' or K_1''.

4. Conclusions

The advantages of this concept, which could be entitled as the "border crossing" concept, are obvious and quite convincing. In general, this concept could be stated as follows:

a) "inward" transition of the boundary of the gassy area, i.e. transition from the area with fresh air to the hazed working, is complicated due to the adding of $K_1'$and K_1'';

b) if the further displacement of the miners through the gassy area is still a better choice, it does not create additional complications until miners reached out the other boundary of the gassy area (from all the expressions for determining $P(j,i_k) \Rightarrow C(j,i_k)\neq 0$ K_1 is excluded; but this is applicable to $P(i_k, j)$);

c) "outward" transition of the boundary gassy area is facilitated by the restoration of the parameters K_1' and K_1'' for $\forall$ $(i,j) \Rightarrow C(i,j)=0$, adjacent to the boundary, in the expressions for determining $P(j, i)$.

Thus, a discussion has been offered, in addition to requirements [1], a proposal for possible correction of emergency escape routes, partially alternating their areas with fresh air and hazed areas, of course, provided that the emergency situation is under control.

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ЗНИЖЕННЯ РИЗИКУ ЕВАКУАЦІЇ ГІРНИКІВ ПРИ ВИНИКНЕННІ АВАРІЇ З АЕРОЛОГІЧНИМИ НАСЛІДКАМИ

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Анотація. Рух маршрутами евакуації пов'язаний із ризиком різних типів. Перш за все – рух відбувається у прискореному порядку, щоб встигнути здійснити евакуацію протягом оперативного часу плану ліквідації аварій . По-друге – евакуація здійснюється маршрутами, менш впорядкованими у порівнянні з основними маршрутами руху персоналу до робочих місць, і з використанням запасних виходів. По-третє, неухильне дотримання вимог Правил безпеки щодо руху загазованою частиною маршруту до досягнення найближчого свіжого струменю і далі виключно за чистим струменем, у ряді випадків значно подовжує маршрут. Можливим є, наприклад, випадок, коли при використанні пунктів переключення у резервні саморятівники вихід протягом оперативного часу плану ліквідації аварій все ж недосяжний, а організацію другого пункту заборонено Правилами безпеки, тощо. Крім того, ризик аварійної евакуації пов'язаний з тим, що, на відміну від класичних маршрутних задач, маршрути будуються не «від точки до точки», а від початкової множини (позиція плану ліквідації аварій) до кінцевої (множина виходів на поверхню призначених для евакуації шахтних стовбурів). Індивідуальний ризик при цьому різниться для окремих груп гірників, що евакуюються з виробок позиції плану ліквідації аварій. Тому ставиться задача розробки методу зниження ризику аварійної евакуації з можливим (у припустимих межах) порушенням вимог Правил безпеки і коригування цих вимог.

Неухильне виконання вимог Правил безпеки здатне спричинити ускладнення аварійної евакуації. На нинішніх шахтах із складними шахтними вентиляційними мережами великої топологічної розмірності внаслідок виникнення екзогенної пожежі можуть утворитися великі загазовані ділянки, які, при організації аварійної евакуації, здатні викликати певні ускладнення. Обминути їх – значить збільшити час евакуації, і, можливо, не вкластись у оперативний час плану ліквідації аварій.

Запропоновано алгоритм коригування маршрутів евакуації, який, за умови отримання шляхом імітаційного моделювання аварійної ситуації реальної інформації про можливі шляхи евакуації, дозволить скоротити ці шляхи, хоча вони і містять, по черзі, чисті і загазовані ділянки. Алгоритм рекомендовано для обговорення з метою коригування вимог Правил безпеки.

Ключові слова: план ліквідації аварій, шахтна вентиляційна мережа, зона загазування, маршрути аварійної евакуації.

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