RISK FACTORS INDUCED BY INSULATED MINE SELF-RESCUERS ON CHEMICALLY RELATED OXYGEN AFFECTING ON RESPIRATORY COMFORT

Prof. Gryzunov V.V. PhD.[1], student of the 3rd year Dzhemilev E.R.[1], student of the 3rd year Chipura S.I. [1]
Saint-Petersburg Mining University, Russian Federation [1]

bajnnemech2@yandex.ru@mail.com, enver.dzhemilev@mail.ru, s.chipura@mail.ru

Abstract: *The high methane hazard of coal mines, despite safety measures, has led to a change in the structure of fatal injuries. More than 54% of miners die from carbon monoxide poisoning, which predetermines the need to study risk factors when activating a mine self-rescuer with chemically bound oxygen. These factors include normobaric hyperoxia, "nitrogen hazard", hyperoxic hypoxia, high temperature and dryness of the inhaled gas mixture, increasing hypercapnia, increased resistance to ventilation. The current situation predetermined the need to study the tolerability of physical loads when activating the mine self-rescuer. 18 healthy volunteers were examined. The obtained results demonstrated that already from 15 minutes the volume fraction of carbon dioxide begins to increase, indicating the formation of a "break point" of the mechanisms of voluntary control of breathing. The volume fraction of oxygen in the respiratory bag reaches its maximum values by the 25-35 minute and ranges from 96.0 to 97.3% v/v at a barometric pressure of 770.5 ± 1.70 mm Hg. Resistance to breathing during inspiration and expiration during physical exertion reached 77.5 ± 9.95 mm WG and 85.0 ± 9.06 mm WG, respectively, on the 30th minute. At the 40th minute, the aerodynamic resistance to ventilation reaches its maximum value and this zone can be considered as a kind of "reference point", with which deactivating of the self-rescuer due to severe dyspnea begins. Threat also consists in a decrease in the percentage of nitrogen in the gas mixture. Already from the level of 1.7 volume percent of the nitrogen content in the respiratory bag, the mine self-rescuer is deactivated under physical exertion. The main reason for stopping work is the lack of GDS for inhalation, which is probably due to micro-teleclactisation of the lungs and compensatory hyperventilation. Thus, the traditional system of training miners for the use of self-rescuers in emergency conditions does not allow miners to adequately compensate for the effects of negative factors associated with activation of the self-rescuer.*

Keywords: COAL INDUSTRY, TRAUMATISM, CARBON MONOXIDE, POISONING, COAL MINE SELF-RESCUERS, RISK FACTORS, RESPIRATORY PROTECTIVE EQUIPMENT, BREATH

1. Introduction

The Russian coal industry is represented by a rather large range of enterprises for extraction of mineral resources. Coal mining is carried out at 63 coal mines, on which the conditions for the development of coal beds have changed: the volumes of worked out spaces have increased, the depth and length of the working faces has increased. Almost every third mine in Russia mines for coal at a depth of more than 500 m. Russian mines are not only the deepest, but also methane-hazardous. About 85% of miners die during explosions of methane dust-air mixtures. However, despite the decrease in the number of explosions in coal mines, the specific value of fatal traumatism has increased almost threefold (Fig. 1) [1].

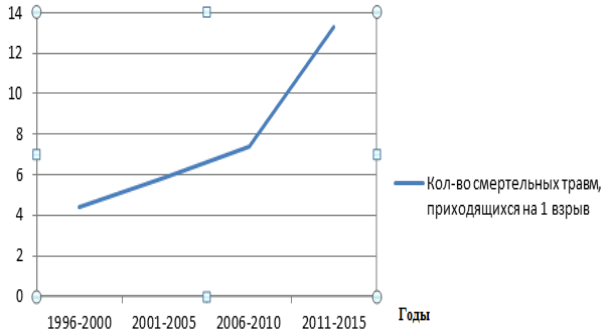

Fig. 1 *The dynamics of quantity of fatal traumas per 1 explosion [1].*

The structure of fatal traumatism has also changed, in which carbon monoxide poisoning dominates. The analysis of major accidents in coal mines showed that 54.5% of deaths occurred as the result of carbon monoxide poisoning. It should be noted that, according to other sources, lethal carbon monoxide poisoning occurs in 32.8 - 49%, and in some cases up to 80% of miners die [2]. It can be assumed that during an emergency situation in a coal mine, miners do not even have time to open and “breathe out” a mine self-rescuer, and in some cases cannot effectively use it. The increase in the length and depth of working is accompanied by large energy losses when leaving emergency areas and increasing of pulmonary ventilation more than 70 L/min, which reduces the protective action time of the self-rescuer almost twice. In addition, any emergency situation is aggravated by the fact that 52% of miners have inadequate behavior, which is the evidence of psychophysiological instability of a number of workers caused by the phenomenon of “professional exhaustion”. It is this phenomenon that can initiate the resistance to malfunctions of systems, equipment, and compliance with safety rules.

2. The prerequisites and means of problemsolution

The current situation is the evidence of the need to study the risk factors induced by the mine self-rescuer with chemically bound oxygen, affecting the respiratory comfort and the time of protective action. In the opinion of domestic researchers [3,4], miners die both when connected to isolating self-rescuers with chemically bound oxygen, and when leaving in mine self-rescuers from gassed working areas for the following reasons:

1) the imperfection of mine self-rescuers with chemically bound oxygen (the trigger device is not always activated, the breathing bag does not open, there is a large resistance to breathing during the inhalation and the exhalation due to the increase of “dead” space, a high temperature of inhaled air resulting from the exothermic reaction is formed);

2) the inability to use them.

In addition, these reasons can also include:

1) the insufficient adaptation of constructive and operational characteristics of a mine self-rescuer to the constitutional features and psychophysiological qualities of miners;

2) the lack of reliable dynamic control of the working condition of the mine self-rescuer;

3) the lack of personal-oriented qualification educational programs of professional training for admission to independent work in coal mines;

4) the personal attitude of miners to mine self-rescuers, as well as ambiguous requirements for their wearing;

5) the lack of individual educational routes for the formation of adaptive model of safe behavior when miners are included in the RPE (Respiratory Protective Equipment) in situations simulating emergencies in the coal mines, during evacuation stages;

In addition, when the miner is connected to RPE, he is affected by negative factors related to the design features and operational characteristics of the mine self-rescuer, the combined and associated effects of which can initiate life-threatening conditions for miners emerging in conditions of gas contamination, smoke, increased temperature. These pathogenic factors include the high temperature of inhaled GRM, which can cause burns of the upper respiratory tract, lungs; increasing resistance during the inhalation and the exhalation in hyperventilation conditions under the physical exertion; normobaric hyperoxia; toxic effects of normobaric hyperoxic GRM (gas-respiratory mixture); hyperoxic hypoxia; the phenomenon of nitrogen washing-out from the human body, which represents "nitrogen hazard"; the dryness of GRM; increasing uncompensated hypercapnia. Psychological and physical exertion in conditions of emergencies in a coal mine are able to potentiate the negative effects caused by connection to the mine self-rescuer. Therefore, it is reasonable to consider in detail the factors caused by the chemical reaction when connected to the mine self-rescuer, negatively affecting the respiratory system and respiratory comfort (Fig. 2).

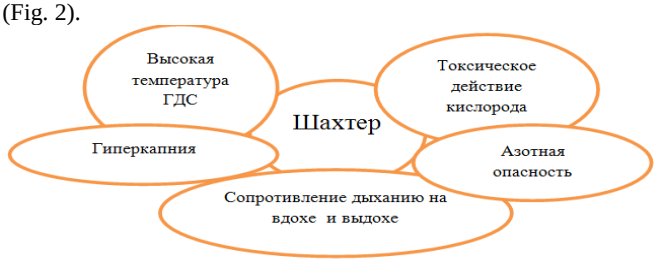

Fig.2. *The main factors of adverse effects on a human induced by the mine self-rescuer.*

3. Results and discussin

Normobaric hyperoxia. As the conducted studies on 18 practically healthy volunteers showed, the volume concentration of oxygen in the respiratory bag when the mine self-rescuer is connected reaches its maximum values by 25-35 minute and ranges from 96.0 ± 1.19 - 97.3 ± 0.56 v/% at a barometric pressure of 770.5 ± 1.70 mm Hg, which allows to say that normobaric hyperoxia prevails in the GRM (Table 1). But within this framework, the volume concentration of carbon dioxide begins to increase from 15 minutes, which indicates the formation of "break point" of mechanisms for voluntary control of external breathing.

Table 1. The dynamics of volume concentration change of oxygen in a gas-breathing mixture

Time, min	1 min	5 min	15 min	30 min	45 min	50 min	65 min
Volume concentration of O_2 (v/%)	52,7± 4,9	60,7 ±3,6	83,0 ±2,6	97,0 ±0,7	95,5 ±1,5	93,6 ±4,6	95,6 ±1,7
concentration of CO_2	0,07± 0,02	0,03 ± 0,01	0,13 ± 0,04	0,54 ± 0,13	0.96 ± 0,39	1,33 ± 0,54	1,46 ± 0,58

The reactions of organism to normobaric hyperoxia can be very diverse, and many issues of the effect of increased oxygen content in inhaled air during physical exertion in healthy people have not been sufficiently studied. Their directivity and intensity depend on the level of partial pressure of oxygen, carbon dioxide, nitrogen, water vapors in the respiratory bag and the duration of phases of respiratory cycle.

The initial reactions to normobaric hyperoxia are usually of an adaptive character and are aimed at limiting the excessive increase of O2 in tissues, especially in the brain, which is very sensitive to the toxic effect of oxygen. It should be noted that the direction of protective reactions is of dual character. The spasm of capillaries, slowing of blood flow induce the development of hypercapia and pH shift to the acid side (metabolic acidosis), which triggers the mechanisms of mitochondrial dysfunction. It completely levels out the defensive reaction of organism. And the physiological adaptive reactions of organism develop into a pathological reaction of toxic effect of oxygen (Fig. 2). Traditionally it is considered that the safe exposure to normobaric hyperoxia for a healthy person does not exceed 2-3 hours. In addition, several researchers note the pronounced variability of individual sensitivity to the oxygen intoxication. The psychoemotional stress, intense physical exertion, hypercapnia can change the sensitivity to the toxic effect of hyperoxia. The pathogenesis of normobaric hyperoxia is due to the toxic effect of oxygen and is associated with the generation of active species of oxygen and nitrogen monoxide (NO). But the imbalance between the antioxidant defense of organism and oxidative stress is in the base of many pathological processes.

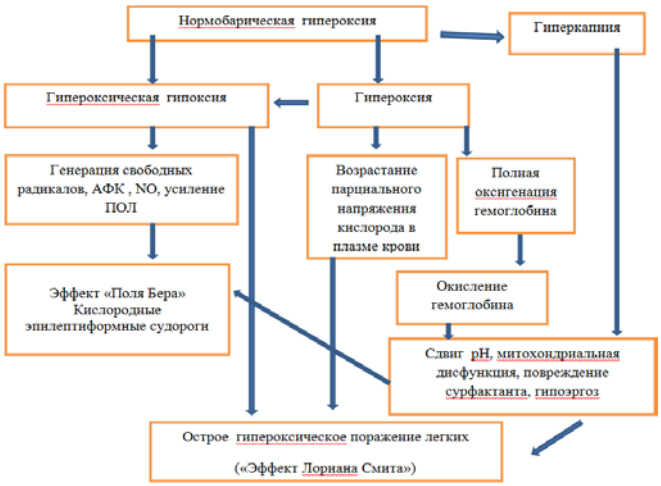

Fig. 3. *General scheme of pathogenesis of normobaric hyperoxia during breathing when one use a mine self-rescuer with chemically bound oxygen.*

Thus, endothelial, mitochondrial dysfunctions, the disruption of surfactant synthesis, alveolar-capillary membrane edema, and microatelectasis contribute to the impaired diffusion capacity of lungs and the decrease of active pulmonary surface. These changes can lead to the development of hypoxia and hypercapia even in conditions of normobaric hyperoxia.

Increased resistance. When testing RPE on volunteers, it was found that the resistance to breathing during the inhalation and the exhalation during physical exertion varied on the first minutes from 26.7 ± 3.33 mm of w.c. to 51.4 ± 2.6 mm of w.c., and, on the 30th minute it reached 77.5 ± 9.95 mm of w.c. and 85.0 ± 9.06 mm of w.c., respectively. (Table 2). However, the resistance to exhalation up to 15 minutes is significantly higher than the resistance to the inhalation, which is largely due to the need to overcome the resistance force of respiratory bag. On the 40th minute, the aerodynamic counteraction to the inhalation (107.5 ± 23.8 mm of w.c.) and the exhalation (97.5 ± 17.8 mm of w.c.) reaches its maximum value and this area can be considered as a kind of "reference point", from which disconnecting of RPE starts because of the shortage of GRM to the inhalation. One of the reasons for disconnecting of the mine self-rescuer is uncompensated hyperoxic hypoxia against the background of physiological hyperventilation, activation of auxiliary respiratory muscular system and switching to the metabolic level of respiratory regulation. But with increasing of aerodynamic resistance, the patients begin to breathe frequently, thereby contributing to the reduction of resistance. However, with frequent breathing, the respiratory volume of the lungs decreases, so the small airways can completely close. The mechanism of dynamic compression of bronchi is due to the fact that with the expansion of lungs, the bronchi are also expanded and their lumen increases.

Table 2. *The dynamics of changes in resistance during the inhalation and the exhalation during the physical exertion using the mine self-rescuer ShSS-TM.*

Min / mm	1	5	10	15
Resistance to inhalation	26,7±3,3	39,7±4,7	56,2±4,9	63,7±5,9
Resistance to exhalation	51,4±2,6	50,0±6,3	70,0±6,5	77,5±8,2
Min / mm	25	30	35	40
Resistance to inhalation	70,0±8,8	77,5±9,9	78,5±13,8	107,5± 23,8
Resistance to exhalation	78,5±9,5	85,0±9,0	95,0±13,2	97,5± 17,8

Therefore, the studied subjects arbitrarily choose the mode of hyperventilation, including the auxiliary respiratory muscular system with increasing energy loss. Such a situation will inevitably lead to a compensatory hyperventilation, and a large absorption of oxygen by respiratory muscles will restrict the limits of physical load.

Nitrogen hazard. Unfortunately, this problem did not find wide coverage in the scientific literature. However, it is well known that when breathing atmospheric air, the dynamic constancy of partial pressure of pO_2, pCO_2, pN_2 is maintained in the alveoli of the lungs, where nitrogen has more than 78%. The partial pressure of nitrogen in the alveolar gas mixture and its partial arterial tension is 76.6 kPa (573 mm Hg), and 1.9 mL of nitrogen is dissolved in 100 mL of blood. In addition, nitrogen penetrates into all tissues, especially fatty and nervous tissues. Therefore, the value of partial pressure level and the nitrogen intensity during breathing in insulating means of individual protection of respiratory organs with chemical bound oxygen acquires special significance. And the phenomenon of "nitrogen absence effect" can be observed when breathing GRM from the mine self-rescuer, which is based on increasing the excitability of the central nervous system, including the respiratory and vasomotor center, which leads to the development of compensatory hyperventilation and an increase in the level of systemic blood pressure. Therefore, the increase in activity of nervous system contributes to the development of energy deficiency under the condition of hyperoxic hypoxia and induces the mechanisms of apoptosis and necrobiosis. In addition, nitrogen acts as a support gas for the lung alveoli. Penetrating through the interalveolar pores of Kona and Lambert's channels, nitrogen provides collateral ventilation. Studies on volunteers demonstrated the tendency to reduce the level of nitrogen in the respiratory bag of mine self-rescuer when breathing gas mixture (Table 3).

Table 3. The dynamics of the volume concentration of nitrogen in the respiratory bag when connected to the mine self-rescuer.

Time, min	1	3	10	15	20	25	30	35	40
V.% nitrogen	46,5	36,3	29,4	16,9	8,5	3,7	2,5	1,8	1,7

And it is from the level of 1.7% v/% of nitrogen content in the respiratory bag that the studied subjects begin to disconnect from the ShSS-TM under the physical exertion. The main reason for the termination of work is the shortage of GRM for inhalation, which is due to microatelectasis.

High temperature of GRM. The temperature of the inhaled GRM of mine self-rescuers can vary within the range (according to the technical data sheets) of 45-55°C, although according to the results of technical trials, the temperature of the inhaled gas fluctuated within the range of 55-72°C. However, even at the temperature of 45-55°C, the thermal denaturation of proteins-enzymes leads to the stop of enzymatic processes. The temperature within the range of 60°C can initiate the change in the state of delocalized electrons of biomolecules and, in particular, induce replication of DNA molecule, which can lead to a pronounced biological effect, and also affect the phase transitions of lipids in cell membranes.

Increase of functional dead space. When connected to the mine self-rescuer, the functional dead space (FDS) is increased due to the heat exchanger and the corrugated tube. But the dead space should be considered not as a static value, but it is reasonable to analyze it from the position of dynamic space, ensuring the constancy of alveolar environment. The analysis of FDS role from the position of adaptation to high temperature of GRM suggests that the increase in the respiratory rate, increasing the "dead space", as well as the additional "dead space", contribute to the evaporation of liquid from the surface of the mucosa of upper respiratory tract, mouth, tongue, increases the space volume, which provides a short-term phase of compensation during the thermal adaptation to high-temperature GRM.

4. Conclusion

The basic mechanisms of ventilation disturbance described above only occasionally appear in a pure form. The combination of these processes is much more common. In such conditions, physical exertion in conditions of normobaric hyperoxia does not always improve the saturation of arterial blood with oxygen. However, breathing with the help of RPE promotes intrapulmonary redistribution of blood flow, which can disrupt venous return. Therefore, it is appropriate to carry out the respiratory therapy to all employees who were connected to a mine self-rescuer and got to first-of-the-air in RPE. One of the most promising methods is PEEP (positive end expiratory pressure). The method is used for spontaneous breathing. The PEEP regimen affects not only breathing but also a circulation and a water-electrolyte balance.

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