Petroleum and Coal

Article **Open Access**

FEATURES OF APPLICATION OF RESPIRATORY ORGANS PERSONAL PROTECTIVE EQUIPMENT WITH CHEMICALLY BONDED OXYGEN BY MINERS IN COAL MINES

Vladimir Victorovich Gryzunov[1], Victor Nicolayevich Kosterenko[2], Sergey Ivanovich Chipura[1], Enver Ruslanovich Dzhemilev[1]

[1] St. Petersburg Mining University, Vasilievsky ostrov, 5, 21 LiniyaStr., 199106, St. Petersburg, Russia
[2] SUEK, 53/7, Dubininskaya str, 109028, Moscow, Russia

Received September 15, 2017; Accepted December 1, 2017

Abstract

The need for development of scientifically based methods of mine self-rescuer use and application is largely determined by the high level of miners' deaths from carbon monoxide poisoning. According to the data from different authors, 33-80% of miners' deaths are due to CO poisoning. The current situation has initiated the feasibility of analyzing the condition of vital functional systems when using mine self-rescuer. To this end, 84 men between the ages of 24 and 59 years having a background in the coal mines and use of mine self-rescuer have been inquired. As a result of the simulation of physical exertion performed by miners when leaving an emergency site using respiratory insulating personal protective equipment, it was found that only 20% of the total number of inquired persons left on the surface for the "estimated time" as per the legend. Among those 80% of the inquired persons the research was discontinued due to the self-rescuer resource end, or as clinically indicated (23%), which was due to the high temperature of a gaseous mixture (GM), occurrence of tickling and cough feeling. High temperature and dryness of the inhaled gas mixture, reducing the hypoxic stimulus against the background of physical activity are the major external factors causing deterioration of health feeling of inquired persons, and the oral type of breathing, increasing "functional" dead space, hyperventilation with a hyperoxygenated mix that limits the human capabilities and predetermines the feasibility of the development of methods for the effective use and application of mine self-rescuer are referred to internal factors limiting the respiratory system adaptive capabilities.

Keywords: *accidents; self-rescue breathing apparatus; poisoning; carbon monoxide; hyperoxia; hypercapnia; physical exertion.*

1. Introduction

Major accidents in coal mines occur with certain intervals of about 3-4 years [1], inducing the development of a fatal mine polytrauma [2-3]. Over the last 11 years, the value of fatality specific factor at coal enterprises, defined as a number of fatally injured miners per 1 million tons of produced coal during the year, fell from 0.52 men/million tons in 2004 down to 0.053 men/million tons in 2015. However, in spite of the measures taken to improve the industrial safety, the situation in the mining industry is a long way still from perfect [4-6], because 20 men perished at coal producing enterprises controlled by Russian Technical Supervision Service (Rostekhnadzor) in 2015 only. Although 9.5 bln. Rubles were spent to ensure safe labour conditions using the funds of the Social Insurance Fund in 2015.

According to the data from Rostekhnadzor, over the past 10 years, about a quarter of entire accidents were associated with the explosions of methane, coal dust, wherein more than 80% of workers perished of the total number of fatally injured men in accidents at coal mines over the above-mentioned time period. According to forensic reports, as a result of dust and gas explosion, 47-58% of miners perish in consequence of affecting factor complex and combined

effects, and 33-46% of deaths and more (up to 80%) were due to carbon monoxide poisoning [7], which is indicative of an insufficient effectiveness of Respiratory Protective Equipment (RPE) implementation and use during emergency situations. Therefore, the effective use and application of mine self-rescuer by miners is the only chance to survive in case of a mine accident.

2. Methodology

The current situation determined the feasibility of analyzing the human breathing habit when using RPE with chemically bonded oxygen during physical exertion in order to improve the efficiency and safety of mine self-rescuer application. With this end in view, 84 men between the ages of 24 to 59 years, who had experience in the use of mine self-rescuer and work in coal mines, were inquired, which made it possible to differentiate the inquired men into four age groups (Table 1). No medical contraindications have been revealed for conducting exercise tolerance test, and the consent to inquiry has been obtained. While performing preliminary inquiry, overweight was noted among 62% of the persons under test, while signs of respiratory function minor disturbances were identified among 4.8% of men.

Table 1. Separation of inquired men according to age groups (x±m)

Age group	Age (kg)	Height (cm)	Weight (kg)	Body-weight index (standard units)
20-30 years (n=22)	25.9±3.1	174.2±7.4	74.8±8.8	24.6±2.4
31-40 years (n=33)	35.3±0.51	175.57±0.87	79.33±1.63	25.72±0.47
41-50 years (n=25)	45.0±0.53	178.1±1.17	84.17±1.99	27.04±0.69
51 years and over (n=4)	58.5±2.5	176.0±1.82	78.0±2.79	25.0±0.4

All the inquired persons were fully equipped in special clothing, underground miners personal protective equipment, and the breath was performed using RPE with chemically bound oxygen. Simulation of physical activities when leaving the emergency mine section was carried out via the treadmill of Eger company (Germany) making it possible to vary the speed of movement and change the angle of inclination. When conducting research, the functional state monitoring of a life-saving system of a person under test was being carried out.

The length of the distance covered varied from 807 to 3,230m, the treadmill elevation angle ranged from 1.7° to 14°, and the speed varied from 24.5 to 70.4m/min. The level of physical exertion regarding energy consumption corresponded to the average one with 82% of the inquired persons, and heavy and very hard work, requiring periodic stress relief or rest, represented the situation with the others, as well as ranged from 623 to 1,319Wh. It should be noted that the route length in the older age group was 13.5% higher than the similar parameter in the age group from 20 to 30 years, although the movement time did not differ differed significantly.

Table 2. Physical exertion characteristics (x±m)

Age group	Route length, m	Actual movement time, min.	Load, Watt-hour
20-30 years (n=22)	2,286.45±148.5	46.68±1.76	923.66±47.46
31-40 years (n=33)	2,451.13±113.2	50.14+1.54	709.3±34.54
41-50 years (n=25)	2,305.6±145.08	49.0±2.07	605.81±29.67
51 years and over (n=4)	2,644.3±353.64	44.75±1.03	466.75±58.66

The effective movement time in RPE ranged from 33 to 87 minutes. Only 20% came onto the surface as per the legend of those inquired persons for the estimated time, and the research was discontinued of 80% of the inquired persons because of the life self-rescuer (57%) resource end, or upon therapeutic indications (23%). Refusals of conducting further researches were caused by the temperature increase of the breathing gas mixture (BGM), increase of the breathing resistance due to the presence of corrugated tube on the self-rescuers, functional space not directly involved in the breathing process, BGM insufficient

humidity, leading to appearing the feeling of throat irritation and cough when breathing with the help of self-rescuer, although the ventilation conditions in RPE are normalized according to GOST R 12.4.220-2001 (Table 3).

Internal and external factors that significantly affect the breathing "comfort" (Tables 3 & 4) are being formed when using the mine self-rescuer with chemically bonded oxygen. The increase in "functional" dead space, increase of breathing resistance leads to growth in load on the breathing muscles, energy expenditure increase, and, as a consequence, decrease in the volumetric rate of expiratory and inspiratory flow, which is compensated by the growth of respiratory movement amplitude and raises the risk of trachea membranous portion prolapse.

Table 3. External factors affecting the breathing "comfort" and their consequences

External factors affecting the conditions of breathing "comfort"	Consequences
• gaseous mixture high temperature; • gas mixture dryness; • increased breathing resistance; • relative normobaric hyperoxia; • insufficient moisture of gas-breathing mixture.	• excessive liquid evaporation from respiratory passages mucous (up to 400 mL/day are normally lost); • mucociliary clearance violation; • hypohydration, hypovolemia; • desudation; • thermal dyspnea; • risk of upper respiratory tracts mucous damage.

Table 4. Internal factors affecting the breathing comfort, when using RPE and their consequences

Internal factors affecting the breathing "comfort"	Consequences
• -mouth type of breathing; • -increase of "functional" dead space; • -hyperoxia; • -hyperventilation.	• Initiates the nasal modulation insufficiency of the breathing system central regulation; • reducing the sensitivity of the respiratory center neurons to hypoxic and hypercapnic stimuli; • violation of toning the throat muscles, tongue before inhalation; • risk of tracheobronchial dyskinesia origin • increase of energy expenditures due to increasing the load on the breathing muscles; • increase in oxygen debt; • emergence of a metabolical "tail"; • reduction of hypoxic and hypercapnic stimuli pulsation amplitude; • changes in the lung tissue diffusion capacity; • increase in the concentration of free radicals and alteration of extracellular and intracellular structures; • disproportionate fluid losses; • hyperosmolar hypohydration; • cellular dehydration.

Besides, the dominant mouth type of breathing is able to initiate the insufficiency of the breathing central regulation nasal modulation, which may be accompanied with decreasing the sensitivity of respiratory center to hypoxic and hypercapnic stimuli, violation of toning the throat muscles and the tongue before inhalation. High temperature, insufficient humidity of hyperoxygenated BGM initiates a sharp inhibition of mucociliary clearance and provokes the fits of coughing and the probability of breathing passage "obstruction" development during

exhalation due to occurrence of transient tracheobronchial dyskinesia increases against the background of reduced toning the upper respiratory tracts.

It should be noted that the process of mass transfer across the alveolar-capillary membrane is under the law of A. Fick only in the case when the molecules of transported gas have no charge, and are chemically as well as osmotically inert. However, oxygen and carbon monoxide have such properties highly approximately. Therefore, excess oxygen, interfering with the chains of biological oxidation, initiates the formation of free radicals that initiate origin of various phenomena, including worsening the processes of mass transfer. It should be noted that hypercapnic (excessive elution of CO_2 from the blood) and hypoxic (due to blood enrichment with O_2) stimuli disappear when breathing a gas mixture enriched with oxygen, thereby smoothing the growth of lung ventilation during physical exertion and causing the origin of "metabolic tail."

3. Conclusions

The analyzed mechanisms can limit the physical capability and influence on the effective application and use of RPE that predetermines the need for development of breathing training methods with the aid of mine self-rescuer simulators, enabling varying the resistance during inhale and exhalation, as well as BGM temperature and humidity. We can assume that the above-mentioned pathogenetic factors can initiate the mechanisms of miners unsafe behavior formation generating explicit and implicit preconditions for making mistakes chain.

Thus, high temperature, insufficient moisture of hyperoxygenerated gas mixture being formed during breathing using RPE with chemically bonded oxygen, initiates reduction of the hypoxic, hypercapnic stimuli, which is accompanied by the development of premature fatigue of breathing muscles during physical exertion against a background of growing resistance to gas mixture flow during intake of breath and exhale, and promotes formation of conditions for shaping unsafe behavior in emergency situation. Current situation determines the need for and feasibility of developing a system of training miners breathing in respiratory protective equipment with chemical bonded oxygen, because the existing system of preparation of the mine self-rescuer for use does not fully meet modern requirements associated with human behavior in emergency.

References

[1] Gryzunov VV. Qualitative analysis of accidents at mining enterprises of the Russian Federation. Scientia. Tekhnika, 2016; 3: 14-18.

[2] Sarkisov AA. Phenomenon of perception of risks associated with nuclear energy by public con-science. Scientific and technical reports of SPbSPU, 2012; 2(3): 9-21.

[3] Gryzunov VV, Shcherban AO, Gryzunova IV. Human error morphogenesis. Engineering sciences: modern view of studying the contemporary problems, Astrakhan, 2016: 1: 116-124.

[4] Matvienko NG. Ensuring safety of gas-containing solid minerals fields development. Labor safety in the industry, 2014; 1: 30-32.

[5] Zaburdyaev VS. Methane rich mines: gas content, methane release, degasification. Occupational safety in industry, 2012; 11: 28-39.

[6] Zaburdyaev V.S. Methane hazard of coal mines. Labor safety in the industry, 2013; 8: 60-64.

[7] Fistal EY, Soloshenko VV. Modern possibilities and results of treatment of miners affected by coal-methanol explosions. Medicine of emergency conditions, 2009; 3-4: 22-23

To whom correspondence should be addressed: Sergey Ivanovich Chipura, St. Petersburg Mining University, Vasilievsky ostrov, 5, 21 Liniya Str., 199106, St. Petersburg, Russia