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ASSESSMENT OF PROFESSIONAL RISK CAUSED BY HEATING MICROCLIMATE IN THE PROCESS OF UNDERGROUND MINING

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The paper reviews the possibility to apply probit-function to assess professional risks of underground mining under conditions of heating microclimate. Operations under conditions of heating microclimate, whose parameters exceed threshold criteria, can lead to dehydration, fainting and heat stroke for mine workers. Basing on the results of medico-biological research on the effects of microclimate on human body, the authors have assessed probabilistic nature of excessive heat accumulation depending on heat stress index.

Using Shapiro-Wilk statistics, an assessment has been carried out in order to test correspondence of experimental data on heat accumulation in the human body to the normal law of distribution for different values of heat stress index, measured in the process of underground mining operations under conditions of heating microclimate.

The paper justifies construction of a probit-model to assess professional risks caused by overheating for various types of underground mining operations, depending on their intensity.

Modeling results have been verified by way of comparison with a currently used deterministic model of body overheating. Taking into account satisfactory convergence of results, the authors suggest using probit-model to assess professional risks of overheating, as this model allows to obtain a continuous dependency between professional risk and heat stress index, which in its own turn facilitates a more justified approach to the selection of measures to upgrade working conditions of personnel.

Key words: professional risk assessment, heating microclimate, labor protection, probit-model, heat stress index, heat accumulation, underground mining, overheating

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Introduction. Methods of professional risk assessment and control, used in modern safety management systems, allow for early detection of hazards to health and life of personnel and their timely prevention in order to upgrade working conditions and safety at the enterprise. Risk assessment is an efficient tool to prevent accidents at hazardous industrial facilities, health and safety incidents and professional diseases.

In the process of underground mining, e.g. development of coal and oil deposits, an important factor of industrial environment is microclimate of underground mine workings, characterized by elevated temperature and air humidity in the operational zones. According to research data [12, 13] and performed special assessment of working conditions, air temperature can reach the values of 38 °C, relative humidity – 85 %.

Operations under conditions of heating microclimate provoke tension in various functional systems of the human body. Heating microclimate parameters can have the following effect on the workers: feeling unwell, decline in performance and productivity; an excessive overheating can even lead to death as a result of a heat stroke [5, 15, 18]. It has also been established that in the long term the influence of heating microclimate increases the risk of death from cardiovascular diseases [12].

The most widely used method of professional risk assessment for underground mining operations is the matrix method, attractive in its simplicity. The idea behind it lies in obtaining risk value from the matrix as a combination of two parameters: frequency, or probability, of the negative event and potential consequences of its occurrence. Usually, probability and severity of consequences are determined using the method of expert evaluations and data on previous accidents and diagnosed professional diseases. The drawbacks of this method come down to subjectivity of frequency and probability evaluations, as well as to impossibility of professional risks assessment with a sufficient degree of precision, as it results in cumbersome risk matrices [9, 19].

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Another method, used for professional risk assessment, is described in the Guidelines R 2.2.1766-03 [10]. However, the criterion for professional risk assessment within this method is its categorization depending on the class of working conditions, based on the index of professional diseases, which significantly reduces the applicability of this method at enterprises with no diagnosed cases of occupational illnesses.

The purpose of this research is to develop a method of professional risk assessment under conditions of heating microclimate; on the one hand, the method must offer higher precision of risk assessment as compared to the matrix method, on the other hand, it should be applicable under industrial conditions.

Research methodology. A method based on probit-function has found a wide application in the practice of risk assessment of accidents and fires at hazardous industrial facilities. This method is mentioned in a scope of regulatory documents on industrial and fire safety, e.g. in the Decree by the Ministry of Civil Defense, Emergencies and Disaster Response from 10 June 2009 N 404 «On Validation of the Procedure to Calculate Fire Risks at Industrial Facilities», in the Decree by Federal Service for Environmental, Technological and Nuclear Supervision from 11 April 2016 N 144 «On Validation of Safety Guidelines «Methodological Principles of Conducting Hazard Analysis and Assessing Risk of Accidents at Dangerous Industrial Objects».

For instance, when assessing consequences of accidents at hazardous industrial facilities and influence of hazardous factors, the probability of human exposure and damages to buildings and constructions is expressed as follows [16]:

$$P = f\left[Pr(D)\right], \quad (1)$$

where $Pr\ (D)$ – upper limit of the integral function under the assumption that the stochastic value, characterizing results of damages, has a normal distribution:

$$P = f\left[Pr(D)\right] = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Pr} e^{-\frac{t^2}{2}} dt. \quad (2)$$

In general case, probit-function takes the form

$$Pr(D) = a + b \ln D, \quad (3)$$

where a and b – constant values, depending on type and parameters of the negative exposure; D – dose of negative exposure.

To justify the applicability of probit-model for professional risk assessment under conditions of heating microclimate the following steps have been taken.

1. As a metric of heat load on the human body in the process of underground mining operations (argument of probit-function), it was decided to choose WBGT index, widely used in international practice, or its Russian analogue – heat stress index. These indices take into account combined influence of microclimate parameters (temperature, humidity, air velocity and heat radiation) on the human body and are numerically equal in cases, where there is no solar radiation [2, 11, 17]:

$$\text{WBGT} = \text{HSI} = 0.7t_{\text{w}} + 0.3t_{\text{g}}, \quad (4)$$

where t_{w} – temperature measured with a wet-bulb thermometer; t_{g} – temperature inside the black globe (Vernon globe).

2. As a metric of exposure, it was decided to use body overheating, characterized by tension of thermoregulating reactions [1, 7], because when the threshold values of heat stress index are exceeded, operations under conditions of heating microclimate lead to body overheating, which is driven by accumulation of excessive heat.

Overheating (accumulation of heat in the body) ΔQ was calculated according to formula [6, 8]

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$$\Delta Q = C\Delta T_{av}, \quad (5)$$

where C = 3.48 kJ/kg – thermal capacity of human tissue; ΔT_{av} – changes in average body temperature over the course of a working shift, °C.

3. Basing on the results of medico-biological research on the effects of microclimate on human body [1, 14], values of ΔQ, calculated for different participants of the experiment, have been arranged in groups according to equal values of heat stress index. An apparent conclusion was that heat accumulation in the bodies of different workers has a probabilistic character, assuming that they operate under the same thermal conditions and perform the work of similar intensity (in publications [1, 14] only male workers have been considered; sample size – from 3 to 7 persons).

Verification of a normal distribution hypothesis for ΔQ (as a stochastic value) was performed using Shapiro-Wilk statistics [4]. Its results showed that with the probability of 0.8 the distribution of ΔQ is normal, which in its own turn allows to use the model based on probit-function for professional risk assessment.

Results and discussion. Using data from medico-biological research [1, 14] and software product IBM SPSS Statistics, parameters of probit-model have been calculated that allow to predict professional risk, associated with heating microclimate, which causes human bodies to accumulate heat equal to or greater than 7 kJ/kg, characterized by some researchers as «excessive» tension of thermoregulating reactions and, consequently, as a critical risk of body overheating (see Table) [1, 6, 7].

Effect of workplace heat load on functional state of the human body

Class of working conditions according to R 2.2.2006-05	Exceedance of the optimal level of heat stress index (upper limit)	Thermal state parameters		Risk of body overheating according to MUK 4.3.2755-10
		Accumulation of heat in the body, kJ/kg (upper limit)	Tension of thermoregulating reactions	
1	–	±0.87	Very low (minimal)	Absent
2	3.0	2.6	Low	Low
3.1	3.3	2.75	Moderate	Moderate
3.2	4.2	3.3	Significant	High
3.3	5.5	4.0	Strong	Very high
3.4	8.0	5.5	Very strong	Extremely high
4	>8.0	≥7.0	Excessive	Critical

It should also be noted that calculations were carried out for workers, conducting operations of similar intensity, which can be classified as IIb. This category includes operations with energy expenditure in the interval 201-250 kcal/h (233-290 W), related to walking, moving and carrying objects up to 10 kg, i.e. associated with moderate physical exertion [11].

Probit-model equation takes the form

$$P = -109.339 + 31.993 \ln HSI, \quad (6)$$

where HSI – heat stress index, °C.

Calculated parameters of probit-model allowed to evaluate the risk of «excessive» tension of thermoregulating reactions for fixed values of heat stress index.

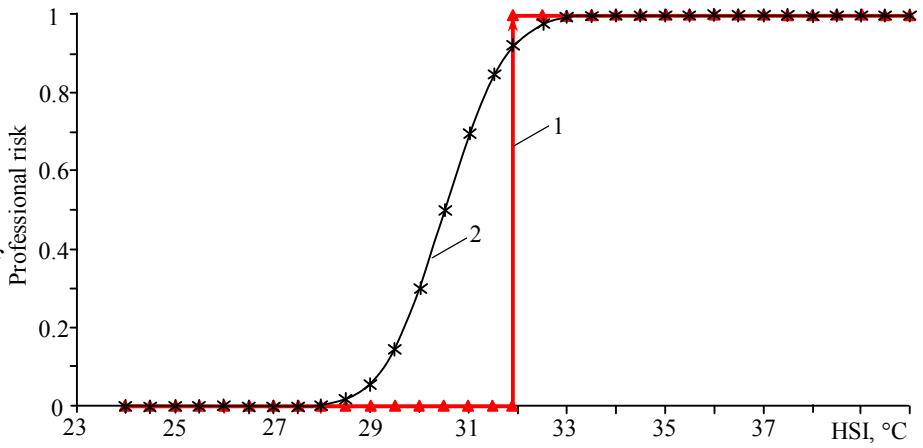
Obtained results have been verified by way of comparison between calculations of professional risk by method of probit-function and evaluation of deterministic criterion of critical overheating P_D, assuming the following values:

$$P_D = 0 \text{ if } \Delta Q \le 5.5 \text{ kJ/kg},$$

$$P_D = 1 \text{ if } \Delta Q > 5.5 \text{ kJ/kg}.$$

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Results obtained for two calculation models are presented in the figure. As the optimal interval of heat stress index for IIb category of operations intensity has an upper limit of 23.9 °C [11], the minimal value of heat stress index, corresponding to «excessive» tension of thermoregulating reactions and critical overheating, equals 31.9 °C.



Professional risk assessment of excessive body overheating for IIb category of operations intensity
1 – deterministic model; 2 – probit-model

Comparison between results of overheating risk assessment using probabilistic and deterministic models demonstrates a theoretical possibility to use probit-function method to assess professional risks of body overheating. The advantages of this method include a relatively simple form of calculation model, applicable under industrial conditions, and the possibility to obtain a continuous dependency between risk and heat stress index. Apparently, one disadvantage of this method is the need to process large amounts of medico-biological data in order to make modeling results reliable. This is an objective difficulty, originating from the very idea of the method, which requires statistically significant sample sizes.

Conclusions

1. Obtained results serve as an illustration that probit-function can be used as a tool to assess professional risks, caused by heating microclimate.

2. Currently the Labor Code of Russian Federation specifies employer's duty to organize and maintain the system of safety management. Professional risk management as a complex of interrelated measures, acting as elements in the safety management system, is aimed at reduction of risks to their threshold criteria. Bearing this in mind, greater precision of risk assessment provides an opportunity of a better justified selection of measures to reduce risks, not least from the position of economy.

3. It is feasible to continue research on the assessment of professional risks, caused by heating microclimate in the process of underground mining, in order to obtain more detailed probit-models for all categories of thermal states.

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