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Analysis of Occupational Accidents at the Mining Enterprises of the Northern Regions of Russia

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Abstract: On the basis of analysis of occupational accidents at mining and oil-and-gas enterprises, it has been established that the level of occupational accidents has a seasonal nature. Logical seasonal variations of accident rates have been considered, not only taking into account durations of stay in difficult weather conditions, but also changes of the general energy consumption of the workers, which depend on the temperature factor in the resident region. On the basis of analytical research on changing energy consumption of work in various climatic zones, mathematical formulas have been derived for definition of duration of physiologically necessary rest, which depends on the temperature factor for different works. Comparison of results of calculations employing the methodology of estimation of labor's gravity with results of experimental data from other researchers has shown more than satisfactory convergence. This has formed the basis for development of the new energy criterion for estimation of danger in receiving injuries by workers in difficult weather conditions. The estimation of an existing scale of labor's severity (energy consumption) by means of a new criterion has shown that there are limiting temperatures, which change the normative category. Nowadays, this factor isn't considered at the certification of workplaces, although there is a close connection between the danger of receiving injuries during work and its severity. For evident representation of change of labor's severity, which depends on the temperature factor, maps have been constructed, similarly to maps of climatic division into districts (zoning). The new indicator of thermal loading, measured in «hour-degree», has been proposed for a more objective picture. Construction of maps has been done for northern areas of the country, where the estimation of energy costs change from temperature is most expedient. Usage of these maps in an aggregate with the executed calculations will serve as the basis for development of a new methodology of workplace certification that further leads to a decrease in industrial traumatism at enterprises of northern regions.

Key words: Labor protection · Occupational accidents · Temperature factor · Severity of work · Energy consumption

INTRODUCTION

Many scientific studies have been dedicated to occurrence of workplace injuries and occupational diseases in various fields of industry [1-5], yet the amount of research covering health risks and necessary precautions to be taken in order to prevent those risks in the area of mining is insufficient.

In Russia, the main energy reserves are concentrated in the northern regions, which are also zones of higher risk of occupational diseases and injuries. According to the criteria of zonation adopted in Russia, these regions are carried to the absolute, extreme discomfort zone by the rate of discomfort residence [6].

Temperature is one of the most significant factors influencing the labor productivity (efficiency) and safety of operations. It is known [7] that the action of cooling the micro-climate decreases possibilities of realization of the physical work: Realization of hard work becomes tedious even for 2–3 minutes. When the temperature of muscles is lowered to 27 °C, sensitivity of muscular receptors decreases by 50 % from normal and at a

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temperature of 15–20 °C, it disappears completely. These changes reduce coordination and can lead to increased quantity of accidents, especially with manual labor in cold conditions. We have not yet elucidated the connection of temperature parameter with the level of occupational accidents at the mining enterprises of the northern regions in the analysis of literature sources. Basically, researchers investigated the effect of low negative temperatures and accompanying climatic factors on the increase in days of disability at the expense of increased occupational diseases [8-10]. The purpose of our research is to develop practical recommendations for reducing injuries at the mining enterprises on the basis of change of traumatism level out of the thermal factor.

Estimation of Influence of Thermal Factor on Danger of Injury: According to the analysis of injuries in mining and oil-and-gas industry enterprises, it was established that incidence of accidents increases with reduction in temperatures. In this case, there is direct dependence between average monthly temperature of air and the total number of injuries, regardless of working place. Change of the level of occupational injuries, which depends on the temperature factor, has been tracked for four seasons. We have taken the number of accidents that occurred in summer as the allowable value and have introduced the factor, showing what extent the number of accidents in the reporting season is in excess of the allowable value.

$$Kn = \frac{Nc}{Nd} \qquad (1)$$

where Kn the factor showing what extent that the number of accidents in the reporting season is in excess of allowable value, Nc is the quantity of accidents for the given period of year; and Nd is the admissible quantity of accidents (summer value conditionally is accepted).

Results of the analysis are shown in Figure 1. The coefficient (factor) in spring is higher than in autumn, although the average air temperature in the spring is higher. This can be explained by the fact that after the winter, when there is maximum intensity and power consumption of work, weariness collects, attentiveness decreases and the probability of accidents increases accordingly. In the autumn period, after the summer holidays, employees tolerate load better, which is associated with increase of energy intensity of the working process.

Analyzing the results, which are represented on the diagram, it is possible to ascertain that the quantity of accidents essentially increases in the cold season.

For more formal estimation of influence of the thermal factor on hazard of receiving injury, it is proposed to use not the absolute values of temperature, but the relative ones. In particular, it is proposed to introduce an index that characterizes the excess (deviation) of seasonal temperature indicators from the comfortable, for which we will conditionally accept also temperature during summer period (Kt). The value of this parameter can be determined by equation (2) [11]:

$$Kt = |1 - t_c/t_b| \qquad (2)$$

here Kt is the index that characterizes the excess (deviation) of seasonal temperature indicators from the comfortable; t_c is the prevailing temperature in °C; t_b is the basic (comfortable) temperature, in this case it is the temperature in summer in °C.

It is more expedient for the integrated estimation of influence of the temperature factor on the quantity of accidents to construct a factor of the seasonal change of accidents that combines the previous two factors.

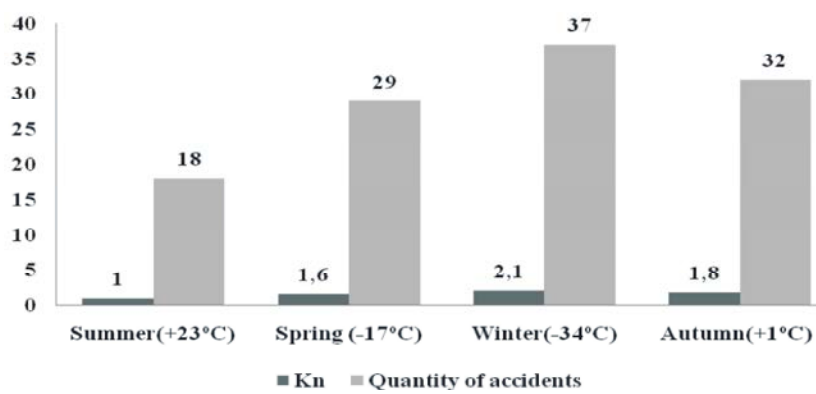

Fig 1: Exceeding quantity of accidents at different times of the year admissible value (summer value)

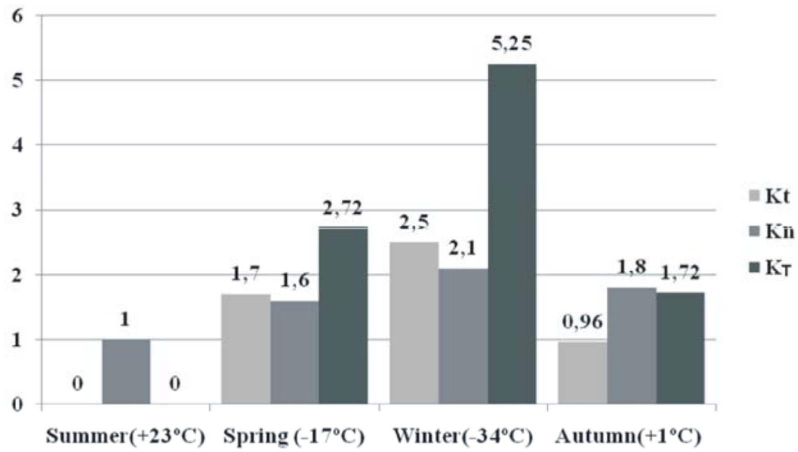

Fig 2: Change of Ccoefficient K_T

Coefficient of seasonal change of accidents (K_T) shows that the quantity of accidents changes with decreasing temperature:

K_T = Kt*Kn

Results of calculations are presented in Figure 2.

From the diagram it is apparent that there is general regularity of change of the quantity of accidents due to the thermal factor.

Estimation of Influence of the Thermal Factor on Energy Consumption of Working Processes: Accidents at enterprises occur with employees, whose work is characterized by high severity and intensity, requiring significant energy consumption. There is high likelihood that the effect of harmful and dangerous factors, which were the causes of injuries, increases the effects of the temperature factor. Many researchers have noted that at work in the conditions of low negative temperatures, intensity of work is much higher than under normal conditions, because there are additional energy consumption, which are going on overcoming the resistance of bulky warm work clothes and also because of general technical reasons, which are caused by complication of operation of mining engines and mechanisms in low negative temperatures [10-12].

The formula for definition of percent change of energy working cost, depending on the temperature is given in equation (3) [12]:

$$P_з = (1 - Э_p(t_B)/Э_p(t_B^*))*100\% \tag{3}$$

where $Э_p(t_B^*)$ is the energy consumption, which are going to realization this kind of work at the standard air t*, kJ / s. Energy cost of work can be expressed by the formula given in the equation (4).

$$Эр = 167{,}6 - 1{,}154t_B \tag{4}$$

It is convenient to represent the formula (3) in the form given in the equation (5). Let the normative temperature t * = 19 °C. Then, using equations (3) and (4), we will get the parameters given in equation (5):

$$P_з^{/}(t_B) = 1{,}15 - 7{,}9 \cdot 10^{-3} t_B \tag{5}$$

By means of this parameter (equation (5)), it is easy to establish relation between the change of energy cost of operation and temperature and also to define energy consumption on categories of work as given in equation (6):

$$Э_p(t_B) = Э_p(t_B^*) \cdot P_з^{/}(t_B) \tag{6}$$

Energy consumption of an organism required to perform an activity are the main criteria in the categorization of work by severity. All kinds of muscular work on the severity subdivide into the following categories: light (energy consumption during operation are up to 210 J/s), medium (210–315 J/s), heavy (315–418 J/s) and very heavy work, characterized by 418 J/s or more of energy consumption.

It was given the following actual example in the literature source [13]. At the mining enterprise it has been fixed 3 cases of injuries with employees of the same

Table 1: Energy consumption of the worker

Month in which accident occurred	Temperature (°C)	Standard energy costs (kJ/s)	Calculated energy costs (kJ/s)
August	+23	0.366	0.354
October	-4	0.366	0.418
December	-37	0.366	0.520

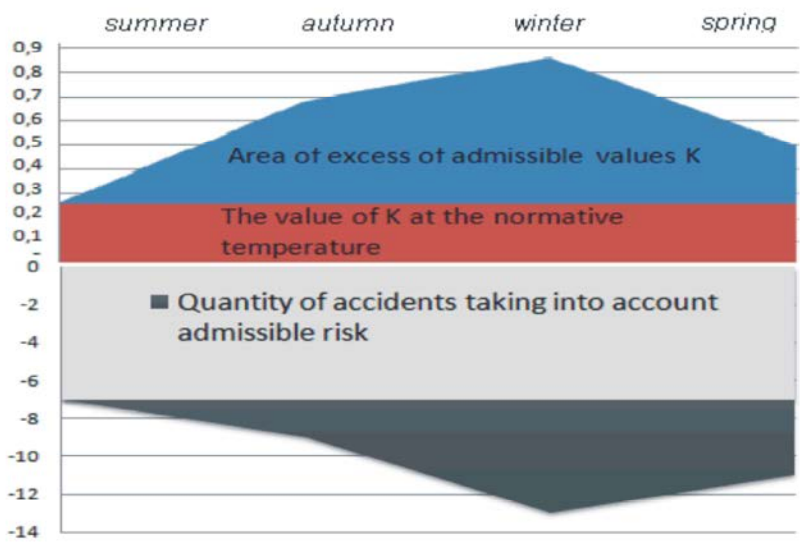

Fig 3: Diagram of dependence of factor K from the season of the year.

profession, whose regulatory energy consumption are 0.366 (kJ/s) and their work is characterized as severe work. Using equation (6), we can calculate the energy consumption, required by an employee to perform his work at different temperatures (Table 1).

Comparing the calculated energy consumption with the normative, we can conclude that the work category of energy consumption changes with temperature fall. Equation (6) also allows establishing the threshold values of temperature, defining a category of work at standardization of its severity. So, at temperature t = - 44 °C easy work passes in work of average severity, at t =-32 °C, work of average severity – to heavy severity and at t =-22 °C heavy – to very heavy severity. Thus, it is obvious that for considered cases, the established standard severity and intensity of work, according to a technique of carrying out of certification of workplaces, doesn't represent the fact that is reflected at the level of actual quantity of accidents too. Changing the category of energy consumption depending on the temperature must be considered in the technique of standardization of work modes. The increase of the general energy consumption of workers leads to reduction of the time of work directly, because the time needed to rest increases. There is the dependence, allowing defining the duration of necessary rest, at various energy consumption of works [14] as given by equation (7):

$$K = \frac{\tau_{rest}}{\tau_{work}} = \left(\frac{Э_p(t_в)}{280} - 1\right) \quad (7)$$

where K is the index, allowing to define duration of necessary rest, at various energy consumption of works, τ_{rest} is the duration of necessary rest; τ_{work} is the duration of performance of work; and -$Э_p(t_B)$-energy consumption defined by the equation (6).

From the simple analysis of this relationship, it follows that it is necessary to change duration of a labor shift in a cold season for reduction of total power inputs and decrease in intensity of work.

If we take the value of the factor (K) calculated at comfortable temperature (t = +19 °C) for conditional normative value (K = 0.26) as seen from Figure 3, there is the area of admissible values, defined by the temperature factor.

The formal analysis of the schedule shows that if we remove the upper area of excess of allowed values, by regulation of rest time and time of work performance, also the area of excess of cases of accidents depending on the thermal factor accordingly will decrease. In turn, it should lead to reduction in the quantity of accidents. Therefore, for increased work safety, it is necessary to normalize work and rest time in dependence not only on the type of work, but also on a temperature mode at which this work is performed. Therefore, during the cold season it is necessary to prolong rest time because during this period energy consumption of works rise and tiredness comes on faster.

The legitimacy of estimation of change of the energy work consumption depending on the temperature is confirmed by comparison with experimental data of other authors, who conducted their research on the effect of combination of negative environmental factors (low temperature, bulky clothes, etc.) on the efficiency and energy consumption of the workers. For example, Repin notices [15] that, at work in the conditions of negative temperatures (t =-2 to -6 °C), the energy costs of construction workers, who perform work of average severity, are higher by 10–30%, than at performance of similar industrial operations during the summer period (t = +12 to +23 °C).

Making Map of Changes in Severity of Work Category for the Northern Regions of Russia: Determination of temperatures that affect the severity of the working process, has given the chance to make map of changes of severity of work category for the northern regions of Russia. Maps have been created taking into account the duration of monitoring temperature, values of which were below the calculated limiting temperatures of change of severity of work. It was proposed to use the indicator of thermal loading, measured in ‘hour-degree’ [hd] for more informative. This parameter indicates the duration of the observation of period with temperatures, which are below limiting values of the severity of work.

The analysis of the data has shown that the indicators of thermal loading are significantly different and change from -1356 [hd] (c. Salehard) to -6335 [hd] (c. Oimyakon). Thus, it is practically established for all mining regions for which there are zones of transition of categories of work and it is not considered in the present study.

CONCLUSIONS

The problem of increased rate of occupational injuries in the North exists, but the authors are convinced that this state can be changed. As other research papers confirm, high rate of occupational diseases and non-compliance with and violation of safety standards are unfortunately a common problem in a wide range of industries in many countries. “Most adverse working conditions were revealed in the following kinds of economic activities: Manufacture of aircraft, metallurgy and mechanical engineering”, says a research paper concerned about health and workplace safety in Perm oblast, Russia [1]. Significant problems with ensuring a safe environment are consistently encountered in a cement factory in Hyderabad, Pakistan. “According to symptoms and signs, out of 100 workers, 58 (58%) workers presented with cough, 69 (69%) workers presented with dyspnea, 33 (33%) of workers presented with tightness of chest, especially at work place, 3 (3%) workers presented with hemoptysis, 5 (5%) presented with weight loss.” [2]. Usage of maps and tables, corresponding with the executed calculations, will serve as the basis for developing of new methodology of certification of workplaces. Further, according to the authors, it should lead to general improvement of working conditions and reduction of occupational accidents at the mining enterprises of the northern regions of the country.

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