A RISK OF PULMONARY DISEASES IN MINERS WHILE USING DUST RESPIRATORS

Purpose. To determine magnitudes of the occupational risks of respiratory disease (pneumoconiosis) occurrence in miners while using filter respirators on the basis of an exposure dust dose with the consideration of work experience.

Methodology. To assess occupational risks, a new approach proposed by the Research Institute of Complex Hygiene and Occupational Diseases is used. The approach is based on determining an exposure dose of a hazardous substance entering the worker’s lungs during their professional contact with it taking into account the volume of pulmonary ventilation, the number of shifts, and work experience.

Findings. Use of dust respirators reduces the risk of occupational respiratory diseases but does not eliminate it completely. It has been established that with more than three-year work experience and coal dust concentrations of more than 50 mg/m³, use of dust filter respirators does not ensure a minimal degree of the occupational disease risks. At the same time, it has been identified that if work experience is less than 3 years with the use of filter respirators, the risk of occupational diseases will be minimal. It has been proved that the risk assessment should involve using the minimal value of a protection factor of a respirator, which is fixed in the workplace environment. It has been shown that working within the areas with dust concentrations higher than 100 mg/m³ is dangerous for miners; over time, with the accumulation of sufficient dust in the lungs it will lead to the development of silicosis.

Originality. It consists in scientific substantiation of the magnitude of occupational risk of respiratory diseases in miners, taking into account a real protection factor of respirators, which is determined at the workplace based on the calculation of an exposure dose and time of professional contact with hazardous substances.

Practical value. The experience of safe operation in mine workings with and without using filter respirators has been substantiated, basing on a safe value of coal dust concentration, at which a low level of occupational risk of respiratory diseases is recorded. Recommendations for determining the dust load taking into account a protection factor of respirators at the workplace have been developed.

Keywords: mine, dust, occupational diseases, pneumoconiosis, risk magnitude, specific dust release, dedusting means

Introduction. It is a well-known fact that the occupational diseases of miners working in underground mines include pneumoconiosis, dust bronchitis, sensorineural deafness, arthritis, radiculitis and others. According to the data by the Centre for Disease Control and Prevention (CDC), the most often occurred disease is pneumoconiosis – a serious lung trouble developed due to inhaling fine-dispersed dust particles with their further absorption by alveolar macrophages with the following emission of cytokines, which stipulates inflammation near bronchioles and alveoli (coal macules), whose further development results in fibrosis (due to accumulated collagen and dilatation of bronchiole walls) with the resulting malignant tumours. As we can see, the consequences of coal dust getting into the workers’ lungs are rather drastic anyway. That is confirmed by the number of studies as for the occurrence of lung diseases caused by entrance of hazardous aerosols [1–5]. For instance, paper [2] indicates that within the period of 1970–2004, 69,277 miners died in the USA while in China up to 5,000 cases of respiratory diseases had been recorded annually up to 2010. Such a situation made the USA Mine Safety and Health Administration, MSHA develop a set of requirements for employers to reduce dust concentration in mine workings down to 2 mg/m³. Nevertheless, within the period of 2000–2006, a growth of dust-factor diseases in miners with more than twenty-year work experience was recorded, which was a significant issue requiring implementation of new hardline approaches to solve that problem [2]. At the same time, in Germany after gradual reduction of a maximum admissible dose from 10 mg/m³ (defined in 1974) down to 4.0 mg/m³ at silicon dioxide content above 5 % in 1991, there arose again the necessity in reconsideration of safe dust doses with specific toxicity to 0.3 mg/m³, provoked by titanium dioxide, whose inhalation results in lung cancer [3].

In terms of Ukrainian mine workings, there are so-called residual dustiness levels that can exceed the maximum admissible ones by ten folds. The latter, by the way, are higher than in the USA and depend on the silicon dioxide content. Such a situation requires implementation of risk control in the system of labour protection management on the basis of international standards like ISO 45001:2018 — Occupational health and safety management systems — A practical guide for small orga-
nizations that stipulates the necessity in hazard identification, evaluation of professional risks, and implementation of preventive measures as for their hierarchy to eliminate or reduce accident probability at the workplace. Moreover, the main requirement of the mentioned standard is a process of constant updating of the labour protection management system on the basis of Deming Cycle.

Basing on the aforementioned, we consider the study aimed at reducing a level of risks of the occupational respiratory disease (pneumological) development to be rather topical.

**Statement of the problem.** European legislation stipulates the priority of the use of collective protective devices over the individual ones. However, the first ones are used by employers depending on the degree of their awareness and finances, which prevents from the reduction of occupational disease risks down to a proper level according to the legislation requirements (e.g. DSTU 2293:2014 in Ukraine). In such cases, legislation determines the use of respiratory protective equipment (RPE). Taking into consideration the fact that implementation of the latter is much cheaper comparing with the collective equipment, the RPE wide use is rather obvious. At the same time, it is essential for RPE selection to assess the probability of occupational disease occurrence in workers while using protective equipment including the specification of safe period of their use.

**Literature review.** Analysis of publications concerning the risks of occupational dust-related diseases showed that there are two contradicting ideas. The first one states that the RPE use reduces their development considerably [4–6]. Thus, paper [4] studies a model of virus transmission by droplet spread use reduces their development considerably [4–6]. Thus, paper [4] studies a model of virus transmission by droplet spread where clinical tests of respiratory protection efficiency involves direct statement that obtained in paper [5], where calculation of the probability of efficiency of respirators at about 90%. Similar conclusions are presented in [4] studies a model of virus transmission by droplet spread where a specific risk is calculated by the formula

\[
R = D_r \cdot R_p \cdot 100 \%
\]

where \( R \) is risk magnitude, %; \( D_r \) is exposure dose during the time of professional contact with a hazardous substance in (mg · shift)/kg; \( R_p \) is relative risk in kg/(mg · shift).

Here \( P < 0.05 \) is insignificant risk;
\( 0.05 \leq P < 0.08 \) is low risk;
\( 0.08 \leq P < 0.1 \) is moderate risk;
\( P > 0.1 \) is high risk.

2. Exposure dose is determined as follows

\[
D_r = \frac{C \cdot Q \cdot N \cdot X}{M \cdot 230 \cdot 25}
\]

where \( C \) is average concentration per shift, mg/m³; \( Q \) is pulmonary ventilation per shift, m³; \( N \) is the number of working shifts per year; \( X \) is a period of professional contact with a hazardous substance, years; \( M \) is body mass, kg.

While determining a total exposure dose, average shift concentration is calculated according to the methodology represented in [7]; in this context, the coefficient of RPE protection \( K_b \) against gaseous substances and solid aerosol particles can be introduced.

3. Relative risk \( R_p \) is the risk per substance dose. Its calculation requires applying the methodology from the practice of identification of chemical substance standards in the environment by the Environmental Protection Agency (the USA) where a specific risk is calculated by the formula

\[
R_p = R_k \cdot M \cdot N \cdot Q \cdot MAC
\]

where \( R_k \) is admissible risk \((1 \cdot 10^{-3})\) [14]; \( M \) is body mass, kg; \( MAC \) is maximum admissible concentration mg/m³.

4. To determine a safe working period with hazardous substances provoking occupational chronic intoxications, one

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should use the data on the admissible and factual exposure doses involving the formula proposed in paper [15].

\[ H_a = MAC \cdot Q \cdot 230 \cdot 3600, \]

where \( C \) is average concentration per shift (mg/m\(^3\)).

Safe operation period is determined from the ratio \( H_a/H_a \).

Research results. The initial stage of the occupational risk assessment involves identifying a hazard for the workers’ health basing on the work specifics and production conditions. The information concerning these factors can be collected from different sources: attestation of workplaces in terms of labour conditions; results of inspections; reports on the workplace control by the health protection authorities etc. However, before determining any results, we should gain insight into numerous factors that are to be considered while studying the aerosol effect on a human organism. Since aerosol is a disperse system consisting of suspended small particles of solid or liquid substances in the air and characterized by different chemical nature, then the consequences from aerosol actions will differ as well. That prevents from generalizing the assessment of occupational risks as retaining of hard particles in lungs results in their injuries and further development of occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxication of the organism systems with the following development of different occupational diseases — pneumoconiosis, while entrance of various toxicants (liquid aerosols) causes additional intoxica...
Both reduce risks of disease development and prolong safe workers’ employment. However, as it has been mentioned earlier, it is hard to implement due to untimely and inconstant use of protective equipment.

For instance, we consider that the coefficient of respiratory protection is 12 MAC; in this context, dust concentration during a shift is constant being 100 mg/m³. Assume that a worker uses PRE for only 5 min per six-hour working shift. Real protection factor will be equal to

$$K_{p, real} = \frac{t_2}{t_1 + \frac{t_2}{K_p}} \approx \frac{360}{5 + \frac{5}{12}} = 10.4,$$

where $K_p$ is protection factor indicated by a manufacturer; $t_1$ is time of a working shift, min; $t_2$ is overall time of the respirator use; $t_2$ is time of the respirator non-use.

We can see that only five-minute non-use of a respirator within a dusty zone has reduced a protection factor by 1.4 units resulting in this case in risk growth by 8% as the exposure dose of dust entering the lungs will increase.

Relying on studies [19, 20], we can state that a share of use of filter respirators is only 60–70% per shift. Thus, real RPE efficiency reaches not more than 3–5 MAC, which increases the disease risk while RPE using by 4 times (Table 2).

While analysing the results of assessment of respiratory occupational disease occurrence represented in Table 2, it should be emphasized that the reduction of the respirator’s protection factor takes place due to incompliance of a half-mask to the facial anthropomorphic features as well, which can be determined at the selection stage, e.g. by applying a fittest. Despite the fact that this test is used mostly for corresponding selection of the best half-mask for a particular worker with a minimal suction coefficient, the identified indices can be also used for calculating a protection factor at the workplace. To do that, a procedure is organized to test tight contact of the RPE half-mask with a face along the obturation line by identifying the points of suction (penetration) of hazardous substances in the form of aerosols (aerodisperse particles, gases, vapours etc.) into the RPE under-mask space.

The aforementioned calculations do not consider variations in dustiness that can influence greatly the coefficient of respirator protection at the workplace per shift. The latter is the determining one for the dust load evaluation.

Assume that the air contamination is about 50 mg/m³, consumption of inhaled air is 0.03 m³/min, and total time of being within the dusty space is 360 min. Then, the amount of dust entering the lungs without the respirator use will be of the value according to NPAOP 10.0.58–04 “Instructions on measuring dust concentration in mines and consideration of dust loads”

$$A_p = 0.001C_iQ_0t_d = 0.001 \cdot 50 \cdot 0.03 \cdot 60 = 0.54,$$

where $C_i$ is dust concentration in the working zone air, mg/m³; $Q_0$ is total air flow through a respirator, m³/min; $t_d$ is time, min.

<table>
<thead>
<tr>
<th>Dust concentration, mg/m³</th>
<th>Protection factor of a respirator with filters of second class of protection</th>
<th>Work experience, years</th>
<th>Exposure dose, g</th>
<th>Risk, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>12</td>
<td>5</td>
<td>$3 \cdot 10^{-5}$</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Note 3 is possible factor of respirator protection if workers will use a protective device for not more than 70% of their working shift.
Let a worker in these conditions use a filter respirator for six hour. In this context, a worker’s protection factor within a five-hour period of constant and correct use is equal to 12 MAC, and within an hour period – 1 MAC due to mask slipping during the work or filter replacement, necessity in speaking or other reasons when the face contact tightness is violated or a mask is taken off. Then the dust load will be equal to

\[
A_d = \frac{0.001}{K_{p1}} C_Q t_1 + \frac{0.001}{K_{p2}} C_Q t_2 + 0.03 + 0.09 = 0.12,
\]

where \(K_{p1}, K_{p2}\) are coefficients of respirator protection 12 MAC and 1 MAC, respectively; \(t_1, t_2\) are time of working wearing a filter respirator with its correct and constant use as well as with tightness violation or taking off a filter respirator, respectively.

The obtained result validates the dependence of dust load on a minimal value of the factor of respirator protection connected with the calculation of an exposure dose while assessing occupational respiratory disease risks. The represented results show that in case of correct, timely, and constant use of a filter respirator during the whole working shift, the dust amount entered the lungs would be only 0.045 mg at the dustiness of 50 mg/m³ during a shift while in case of taking off the respirator even for five minutes, its amount would increase by almost 2.5 times.

The calculations represented in the table show that in terms of admissible exposure dose of 248 g for coal dust with free silicon dioxide content being 5–10 % per year (to compare with, according to NPAOP 10.0-5.08-04 “Instructions for coal dust measurement in mines and dust-load consideration”, this dose makes up 540 g at pulmonary ventilation volume of 0.03 mg/m³) safe working period in a coal mine is not more than one month (at 50 mg/m³ dustiness) while using RPE of second class of protection as well as with sufficient dust mass accumulated in the lungs it results in pneumoconiosis. That requires development of the corresponding regulations in respiratory protection equipment, which would allow having clear specification of dust load basing on risk assessment to be under constant control.

4. Thoroughly selected high-quality dust respirators and their proper use can help reduce the risks down to a low level. The latter requires worker’s shortened staying within the immediate dusty atmosphere as well as skills of correct RPE application.

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References.


Мета. Визначення величини професійного ризику виникнення захворювань органів дихання на пневмоконіоз у гірників при використанні фільтрувальних рес- піраторів на основі експозиційної дози пилу з урахуванням стажу роботи.

Методика. Для оцінки професійних ризиків був ви- користаний новий підхід, запропонований у НДІ комп- лексних проблем гігієни та професійних захворювань, що базується на визначені експозиційної дози шкідливої речовини, яка потрапляє до працівника за час професій- ного контакту з нею з урахуванням об’єму легеневої вентиляції, кількості змін і стажу.

Результати. Використання протипилових респіраторів зменшує рівень ризику виникнення професійних за- хворювань органів дихання, але не ліквідує його зовсім. Встановлено, що при стажі роботи більше 3 років і кон- центраціях вугільного пилу більше 50 мг/м³ використання протипилових фільтрувальних респіраторів не дозво- ляє забезпечити мінімальний ступінь ризику виникнен- ня професійних захворювань. У той же час, встановлено, що при стажі роботи менше 3 років з використанням фільтрувальних респіраторів ризик виникнення профе- сійних захворювань буде мінімальним. Доведено, що при оцінці ризику необхідно користуватись мінімальним значенням коефіцієнта захисту респіратора, що фіксує- ється у виробничих умовах. Показано, що робота в зонах із концентрацією пилу понад 100 мг/м³ є небезпечною для гірників і з часом при накопиченні достатньої маси пилу у легенях це призведе до розвитку силикоузу.

Наукова новизна. Полягає у науковому обґрунтуван- ні величини професійного ризику виникнення захо- ровень органів дихання гірників з урахуванням реаль- ного коефіцієнту захисту респіраторів, що визначається на робочому місці на основі розрахунку експозиційної дози й часу професійного контакту зі шкідливою речо- виною.

Практична значимість. Обґрунтовано стаж безпечної роботи у гірничих виробах як із використанням, так і без використання фільтрувальних респіраторів, виходя- ци з безпечної величини концентрації вугільного пилу, за якою фікуються низький рівень професійного ризику за- хворювання органів дихання. Розроблені рекомендації із визначення пилового навантаження з урахуванням кое- фіцієнта захисту респіратора на робочому місці.

Ключові слова: шахта, пил, професійні захворювання, пневмоконіоз, величина ризику, пиловиділення, за- соби знищення.

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