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Original article

Hygienic assessment of the nature of the labor processes of miners engaged in underground mining polymetallic ore

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Abstract

Working conditions at mining enterprises are determined by the technology of the production process. Modern working conditions for workers are characterized by high dust levels, intense noise and vibration, unfavorable microclimate, a high degree of psycho-emotional stress and heavy physical labor.

***Purpose:** Hygienic assessment of the degree of severity and intensity of the nature of work of miners in underground mining of polymetallic ores, taking into account the performance of various technological operations to predict the risk of health problems and optimize labor.*

***Methods.** The object of the study were miners of underground ore mining at the Zhezkent mining and processing plant of Kazakhmys Corporation LLP in the East Kazakhstan region. Comprehensive hygienic studies were carried out to assess the degree of severity and intensity of labor processes of miners in underground ore mining, taking into account the performance of technological operations.*

***Results.** The results of a hygienic assessment of full-shift time-lapse studies of the nature of the work of miners of various professional groups made it possible to establish that operators of underground mining equipment spent more than 44.2% of their shift time on the main operations of drilling and extracting ore, 38.5% on auxiliary operations, final operations – 5.6%. Miners engaged in fastening the face space, repair work, loading ore onto scraper winches, etc. spent half (54.3%) of their shift time on main operations, about 25.3% on auxiliary work, and 9.5% of their shift time was spent on final works.*

***Conclusions.** Thus, the results of timing studies made it possible to establish that:*

The labor activity of miners in operating mining equipment corresponded to class 3.3 in terms of intensity of labor processes, and class 3.2 in terms of severity. The work of fasteners, drifters and longwall miners, whose technological operations are associated with the performance of non-mechanized types of labor operations, required significant physical effort and corresponded to class 3.3 in terms of the severity of labor, and class 3.2 in terms of labor intensity.

Key words: nature of labor processes, miners, occupational health, occupational risk, mining industry.

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Introduction

One of the key components of sustainable socio-economic development and high labor productivity in society is the health and well-being of working citizens. The recognition of the importance of human capital and its role in driving sustainable growth and innovation across systems has led to the pursuit of new avenues for improving the collaborative efforts of all stakeholders: the healthcare system, the state, society, and employers [1,2].

The work of miners in modern underground ore mines is characterized by the use of a wide range of high-performance machines and mechanisms, which introduce new requirements for labor processes [3,4]. Underground ore mining involves a series of operations to provide access from the surface to ore deposits, including contouring the ore body, creating tunnels, extracting ore, and constructing track systems. Horizontal and inclined mining tunnels are often developed using drilling and blasting methods, where workers sequentially perform tasks such as drilling and loading blast holes, conducting explosive work, clearing debris, loading and transporting blasted material, securing tunnels, and extending tracks, pipelines, and other communications. Various types of electric drills are used during drilling, and blast hole loading is done manually. The removal of blasted material is handled by rock-loading machines. The remaining tasks in the mining cycle - such as securing the tunnel face, laying tracks, and extending communications - are performed manually. The most arduous aspects of this work are the extended walking over long distances, often in inclined tunnels, and the clearing of rock masses.

The working conditions in underground mining are particularly strenuous and demanding, where exposure to high concentrations of dust, vibration, noise, and an unfavorable microclimate is exacerbated by psycho-emotional stress. The constant lack of sunlight, the confined spaces during work operations (which often require uncomfortable postures), and the presence of explosive gases create conditions conducive to health deterioration and the risk of developing occupational diseases [5-7].

It is also important to emphasize that the presence of harmful factors in the working environment (dust, noise, vibration, heat, and low lighting) not only complicates the functional interaction within the "human-work environment" system but also serves as an excessive irritant that poses potential dangers to almost all major functional systems of the body, ultimately leading to an increased risk of occupational diseases [8-10].

According to the classification of mining work by the degree of severity and required rest time, the severity of the tasks performed ranges from light to heavy and very heavy work. Operating machinery does not require significant physiological effort from miners, and preparatory operations are also considered light work. However, performing auxiliary, mostly non-mechanized tasks (such as shoveling, pulling power cables, securing roofs for safety, etc.) leads to significant shifts in the functional state of miners' bodies. The risks of disease are heightened by the cooling microclimate of workplaces, general and localized vibration, noise, dust and gas mixtures, physical overexertion, work in forced and uncomfortable postures, as well as other factors related to the work environment and labor processes.

The most common pathologies that arise during miners' work activities include musculoskeletal and nervous system disorders, vibration disease, neurosensory hearing loss, and respiratory diseases. These health issues are the primary causes of premature reduction or complete loss of professional work capacity among miners [11-14].

The combination of industrial factors in the performance of key technological operations in underground mining determines a high degree of occupational health risk for workers and leads to the development of occupational diseases. Therefore, it is crucial to investigate the cause-and-effect relationship between occupational factors and the health of miners employed in the mining industry from the perspective of occupational risks.

Materials and Methods

The study focused on underground miners at the Zhezkent Mining and Processing Plant, which is part of the Kazakhmys Corporation in the East Kazakhstan region. The underground miners involved in polymetallic ore extraction were divided into two groups: the main group, which included drill rig operators, load-haul-dump machine operators, and scraper operators; and the auxiliary group, which included miners, stope builders, blasters, and underground electrician-mechanics.

To measure the maximum grip strength, a portable dynamometer (DRP-90) was used. For assessing the static endurance of hand muscles, the maximum muscle strength was first determined, after which the subject was instructed to maintain 2/3 of the maximum effort until they could no longer continue the static task. The duration of this effort, recorded in seconds, was used as an indicator of static endurance. Handgrip strength was measured using a stand dynamometer (DS-500).

Functional changes in the cardiovascular system were assessed by central hemodynamic indicators: systolic and diastolic blood pressure (SBP and DBP) were measured using the N.S. Korotkov method, and heart rate (HR) was calculated using a stopwatch by counting the pulse [15].

To evaluate respiratory function, the respiratory rate (RR) and minute ventilation (MV) were recorded using a volumeter, and the maximum voluntary ventilation (MVV) and breathing reserve (BR) were determined.

Comprehensive hygienic studies to assess the nature of the labor processes of the main and auxiliary occupational groups of underground miners were conducted in accordance with the Methodological Recommendations "Hygienic Criteria for Assessing and Classifying Working Conditions Based on the Harmfulness and Hazard of Factors in the Working Environment, and the Severity and Intensity of the Labor Process," approved by the Committee for Sanitary and Epidemiological Control of the Ministry of Health of the Republic of Kazakhstan on December 31, 2020, No. 24 [16].

This work was carried out as part of an initiative research project on the topic: "Predicting Health Disorders in Workers Engaged in the Extraction and Processing of Polymetallic Ores from the Perspective of Occupational Risks" (state registration number 0123RK I 0358 dated September 27, 2023).

Results. Underground polymetallic ore mining at the Zhezkent Mining and Processing Plant is conducted at depths ranging from 800 to 1300 meters. The results of full-shift time-motion studies of the work activities of machine operators involved in underground polymetallic ore mining revealed that during an 8-hour work shift, the preparatory phase included checking mechanical, electrical components, pneumatic systems, and lighting installations. On average, these operations took 17 minutes of the work shift time (Table 1).

Table 1 - Timekeeping of working day of mining machinery control operators at Zhezkent Mining and Processing Plant, (M±m)

Labour operations	Working time costs	
	minutes	percentage
Shift acceptance	17±7	3,5
Preparatory stage: preventive inspection of machinery, replacement of parts, cleaning of nozzles, checking of mechanical, electrical, hydraulic parts, pneumatic systems and lighting systems	27±12	5,6
Main stage: control of mining equipment, drill heads, drilling and own drilling.	212±9	44,2
Auxiliary operations: clearing the ground at the mining equipment, preparation for work	185±12	38,5
Breaks	21±5	4,38
Shift handover	18±6	3,75
Total	480	100

The main stage of the work involved positioning the drill heads at the face of the work area, initiating drilling, and the actual drilling process. During this phase, the driller monitors the water, air, and oil pressure. The primary work area during drilling is the platform at the control panel. The design of the drill booms ensures automatic maintenance of parallelism of the auto-feeders. The feed force of the jackhammer during drilling reaches no less than 1,000 kgf.

The hydraulic system of the drilling rigs is powered by hydraulic pumps driven by electric motors. The drilling rigs are equipped with both working and parking brakes, ensuring effective braking during movement and at rest. Using levers, the driller performs operations such as raising, lowering, and rotating the boom, as well as directing the boom to the face of the work area. The driller then activates the water supply system, the rotary drive, and the striker for drilling and borehole creation to the required depth. The duration of the main stage ranges from 2.2 to 4.0 hours. On average, this stage consumes 44.2% of the shift time.

Table 2 - Timekeeping of the working day of underground miners engaged in manual labour at Zhezkent Mining and Processing Plant, (M±m)

Labour operations	Working time costs	
	minutes	percentage
Preparation of explosives and bonding materials, bringing up the drive, tightening clamps, clearing the ground near mining machines and between frames, loading boreholes with explosives, loading dry mortar manually from the dump truck body into the torquet gun, etc.	120,9 ±12,0	25,2
Scraping and levelling the roof of the formation, crushing large pieces, throwing rock mass on the scraper track, loading rock mass on conveyor belts, fixing the roof with reinforcing bars or reinforced concrete rods, torqueting, etc.	260,5 ±18,2	54,3
Cleaning of the service area, minor repairs of mechanical parts of machinery and equipment	45,5±5,3	9,5
Total	480	100

Auxiliary operations, including clearing the ground at the face of the work area, breaking up rock mass, preparing for loading operations, and transporting the rock mass, account for 38.5% of the shift time.

The final stage: 18 minutes before the end of the work shift, the miners operating the drilling equipment blow out the boreholes, disconnect the water and air hoses, bring the drill carriage to the transport position, and move it to the main parking area.

For clearing the face and loading the rock mass, load-haul-dump machines of types TOR-300 and R-1300 from CATERPILLAR are used. These machines are operated with either electric or pneumatic drives. They have a load capacity of over 5 tons or are powered by a diesel engine with up to 147.2 kW of power. During a shift, the machine dumps 40 buckets onto the loading machines over a distance of up to 10 meters.

For transporting the rock mass to scraper shelves, EJC-417 dump trucks from TAMROK are used. The rock mass is unloaded from the scraper shelf using LS-55 scraper winches into VB-4.5 wagons, which are then transported using electric locomotives.

To extract ore from the chambers, the excavated space is filled with a hardening mixture. The inclined drift is reinforced with yielding arch supports SVP-27, followed by backfilling with concrete, steel rods, and a combination of supports (concrete + chain-link mesh + shotcrete).

The ventilation-backfill layer is expanded by constructing a log crib, followed by the laying of the upper layer. Ore from the last stopes is transferred to the haulage level via the ventilation-rise drift. The backfill mixture is delivered to the clearing operations through a pipeline located in the ventilation-backfill block and cut paths.

Table 3 - Labour severity assessment of mining workers in underground mining of polymetallic ores at Zhezkent Mining and Processing Plant

Labour severity indicators	Drill rig typist	Typist of scraper winches	Typist of loading and unloading equipment	Fixer	Sinker	Mining labourer of the mine face
1. Physical dynamic load (kg m) 1.1 regional load: moving a load up to 1m	2	2	1	3.1	3.1	3.1
1.2 general load: load displacement from 1 to 5 m	1	1	1	3.2	3.1	3.1
2. Weight of lifted and moved load (kg) 2.1 when alternating with other work	2	2	3.1	3.2	3.1	2
2.2 continuously during the shift	2	2	2	3.2	3.1	3.1
2.3 total weight for each hour of the shift	2	2	3.1	3.1	3.1	3.1
3. Stereotyped work movements 3.1 local	3.1	3.1	2	3.1	2	1
3.2 regional load	3.1	2	3.1	3.1	2	2
4. Static load (kgf s) 4.1 with one hand	2	2	2	3.1	2	3.1
4.2 with two hands	2	2	2	3.2	3.1	3.1
4.3 involving the muscles of the body, legs	2	2	3.1	3.2	3.1	3.2
5. Working posture	3.1	3.1	3.1	3.2	3.1	3.2
6. Body tilts (number per shift)	3.1	2	3.1	3.2	3.1	3.1
7. Movement in space (km) 7.1 horizontally	1	2	1	2	2	3.1
7.2 vertically	1	1	1	1	1	2
Severity class of working conditions	3.2	3.1	3.1	3.3	3.3	3.3

Underground miners, during the course of tunneling and extraction operations, engage in both professional and operational forms of labor division.

At the beginning of the shift, underground miners prepare explosives and binding materials, bring in the drive, tighten clamps, clear the ground near the mining machines, and between frames. On average, preparatory work consumes approximately 22.9 to 25% of the shift time (Table 2).

Table 4 - Assessment of the degree of tension of labour processes of mining workers of underground mining of polymetallic ores

Indicators of labour intensity	Drill rig typist	Typist of scraper winches	Typist of loading and unloading equipment	Fixer	Sinker	Mining labourer of the mine face
1 Intellectual workload Work content	3.1	3.2	3.2	2	2	2
Signal perception evaluation	3.1	3.2	3.2	3.1	2	2
Distribution of functions by degree of task complexity	3.1	3.2	3.2	3.1	3.1	3.1
Nature of work	3.2	3.2	3.2	3.1	3.1	3.1
2 Sensory loads Duration of concentrated observation	3.1	3.2	3.1	1	1	2
Signal density per 1 hour of work	2	3.1	3.1	1	1	3.1
Number of production objects of simultaneous observation	3.1	3.1	3.1	2	2	3.1
Load on auditory analyzer	3.2	3.2	3.1	1	1	1
Load on the vocal apparatus	3.2	3.2	3.2	1	1	1
3 Emotional loads Degree of responsibility for the result of own activity.	3.2	3.2	3.2	3.1	3.1	3.1
Degree of risk for own life	3.2	3.2	3.2	3.2	3.1	3.1
Degree of responsibility for the safety of others	3.2	3.2	3.2	3.2	3.1	3.1
4 Monotony of loads Number of elements to realise a simple task	3.1	3.1	3.1	2	2	2
Duration of fulfilment of simple production tasks	2	2	2	2	2	1
Active time	2	2	2	1	1	1
Monotony of the work environment	3.1	3.1	3.1	1	1	1
5 Work mode Actual working day duration	2	2	2	2	2	2
Shift work	3.1	3.1	3.1	3.1	3.1	3.1
Presence of a regulated break	2	2	2	1	1	1
Class of labour conditions in terms of tension	3.3	3.3	3.3	3.2	3.1	3.1

After the extraction and transportation of the rock mass, the workers reinforce the tunnels using hand tools. The primary task of the stope builders involves securing the roof with reinforcement bars, precast concrete rods, loading dry mix manually from the dump truck bed into the shotcrete gun, and shotcreting. Over the course of a shift, stope builders manually construct approximately 12 wooden frames, each weighing 7-8 kg, and install around 40 reinforced mesh panels, each weighing 30-40 kg.

The work of delivering support materials and installing the supports requires significant physical effort, particularly when lifting and installing temporary mechanical supports (weighing between 50 kg and 90 kg) or permanent support elements like heavy metal arches and precast concrete linings. The work of the stope builders involves significant postural strain on the muscles of the back and lower limbs. These primary tasks consume 47.9% of the shift's time budget.

Scraper winches of the LS-55 model are used in the work areas. The scraper winch is installed on scraper shelves in the winch chamber. The chamber is reinforced with non-combustible metal arch supports, the sides and roof are secured with mesh linings, and voids are filled with ore. On the scraper shelves, a ladder is installed on the haulage level, with the walking side protected by a continuous metal barrier. The width of the walking side from the edge of the chamber to the winch was 0.7 meters, with 0.6 meters on the other side for installation work. During a shift, the scraper operator loads between 3 to 10 wagons of ore. Scraping waste, cleaning and leveling the roof of the seam, breaking up large pieces, and shoveling the rock mass onto the scraper track require approximately 25% of the shift's time budget. The primary tasks account for 54.3% of the shift's time budget.

The analysis of the full-shift time-motion study results revealed that the heaviest work was carried out by stope builders, tunnelers, and miners in the stoping face, whose work primarily corresponded to Class 3.3 in terms of labor intensity (Table 3).

Labour activity of machinists on the control of drilling rig, scraper winches, loading and unloading equipment corresponded to the degree of tension class 3.3 (Table 4).

Discussion

The results of the hygienic assessment based on full-shift time-motion studies revealed that the work of operators managing mining equipment is largely associated with high neuro-emotional stress. This stress is primarily due to their high responsiveness to the effects of light, dust, and noise, quick decision-making in emergency situations, and the responsibility for the safety of their team.

For miners in key professions (stope builders, tunnelers, repair workers, and face miners), the work is characterized by excessive physical exertion, leading to early fatigue and significant strain on the neuromuscular and musculoskeletal systems [17,18,19].

Conclusions

The occupational activities of operators managing mining equipment corresponded to Class 3.3 in terms of the intensity of labor processes and to Classes 3.1 and 3.2 in terms of physical exertion. The work of stope builders, tunnelers, and face miners, whose technological operations involve non-mechanized tasks, required significant physical effort and was classified as Class 3.3 in terms of physical exertion and Classes 3.1 and 3.2 in terms of intensity.

Conflict of Interest. The authors declare no conflict of interest.

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All authors have read and agreed to the final version of the manuscript and have signed the copyright transfer form.

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Жер асты полиметаллдық тау-кен өндірісімен айналысатын кеншілердің еңбек процесстерінің сипатына гигиеналық баға беру қызметтері

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Түйіндеме

Тау-кен кәсіпорындарындағы еңбек жағдайлары өндіріс процесінің технологиясымен анықталады. Жұмысшылардың қазіргі жұмыс жағдайлары шаңның жоғарылауымен, қарқынды шу мен дірілмен, қолайсыз микроклиматпен, психоэмоционалды стресстің жоғары деңгейімен және ауыр физикалық еңбекпен сипатталады.

Зерттеудің мақсаты: денсаулық проблемаларының туындау қаупін болжау және еңбекті оңтайландыру үшін әртүрлі технологиялық операцияларды орындауды ескере отырып, полиметалл кендерін жерасты өндіру кезінде кеншілердің еңбек сипатының ауырлығы мен шиеленіс дәрежесін гигиеналық бағалау.

Әдістері. Зерттеу нысаны Шығыс Қазақстан облысындағы "Қазақмыс корпорациясы" ЖШС Жезкент тау-кен байыту комбинатының жерасты кен өндіру кеншілері болды. Технологиялық операциялардың орындалуын ескере отырып, жерасты кендерін өндіру кезінде кеншілердің еңбек процесстерінің ауырлығы мен қарқындылығын бағалау үшін кешенді гигиеналық зерттеулер жүргізілді.

Нәтижелері. Әр түрлі кәсіби топтардың кеншілерінің еңбек сипатын толық ауысымдық хронометраждық зерттеулерді гигиеналық бағалау нәтижелері жерасты тау-кен жабдықтарының операторлары негізгі операцияларға ауысым жұмыс уақытының 44,2%-дан астамын жұмсағанын анықтауға мүмкіндік берді. Ал кен бұрғылау және өндіру, көмекші операцияларға 38,5%, қорытынды операцияларға - 5,6% құрады. Кенжар кеңістігін бекітумен, жөндеу жұмыстарымен, кенді скреперлік жүкшығырларға тиеумен және т.б. айналысатын кеншілер ауысымның жұмыс уақытының жартысын (54,3%) негізгі операцияларға, шамамен 25,3% - қосалқы жұмыстарға, ауысым уақытының 9,5% - қорытынды жұмыстарға жұмсады.

Қорытынды. Осылайша, уақыт нәтижелері мынаны анықтауға мүмкіндік берді: тау-кен жабдықтарын пайдалану кезіндегі кеншілердің еңбек қызметі еңбек процесстерінің қарқындылығы бойынша 3,3 сыныпқа және ауырлығы бойынша 3,2 сыныпқа сәйкес келді. Технологиялық операциялары еңбек операцияларының механикаландырылмаған түрлерін орындаумен байланысты креперлердің, өткізгіштердің және кеншілердің жұмысы айтарлықтай физикалық күш - жігерді қажет етті және еңбек ауырлығы бойынша 3,3 - сыныпқа және еңбек сыйымдылығы бойынша 3,2 - сыныпқа сәйкес келді.

Түйін сөздер: еңбек процестерінің сипаты, кеншілер, еңбекті қорғау, кәсіби тәуекел, тау - кен өнеркәсібі.

Гигиеническая оценка характера трудовых процессов шахтеров, занимающихся подземной горной полиметаллической деятельностью

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Резюме

Условия труда на горнодобывающих предприятиях определяются технологией производственного процесса. Современные условия труда работников характеризуются повышенной запыленностью, интенсивным шумом и вибрацией, неблагоприятным микроклиматом, высокой степенью психоэмоционального напряжения и тяжелым физическим трудом.

Цель исследования: гигиеническая оценка степени тяжести и напряженности характера труда горняков при подземной добыче полиметаллических руд с учетом выполнения различных технологических операций для прогнозирования риска возникновения проблем со здоровьем и оптимизации труда.

Методы. Объектом исследования являлись горняки подземной добычи руды Жезкентского горно-обогатительного комбината ТОО «Корпорация Казахмыс» в Восточно-Казахстанской области. Проведены комплексные гигиенические исследования для оценки степени тяжести и интенсивности трудовых процессов горняков при подземной добыче руд с учетом выполнения технологических операций.

Результаты. Результаты гигиенической оценки полносменных хронометражных исследований характера труда горняков различных профессиональных групп позволили установить, что операторы подземного горнодобывающего оборудования затрачивали на основные операции более 44,2% рабочего времени своей смены. бурения и добычи руды, 38,5% на вспомогательные операции, заключительные операции - 5,6%. Горняки, занятые закреплением забойного пространства, ремонтными работами, погрузкой руды на скреперные лебедки и т.д., половину (54,3%) рабочего времени смены тратили на основные операции, около 25,3% - на вспомогательные работы, 9,5% времени смены - на итоговые работы.

Выводы. Таким образом, результаты хронометража позволили установить, что трудовая деятельность горняков при эксплуатации горного оборудования соответствовала 3,3 классу по интенсивности трудовых процессов и 3,2 классу по тяжести. Работа креперов, проходчиков и горняков, технологические операции которых связаны с выполнением немеханизированных видов трудовых операций, требовала значительных физических усилий и соответствовала классу 3,3 по тяжести труда и классу 3,2 по трудоемкости.

Ключевые слова: характер трудовых процессов, горняки, охрана труда, профессиональный риск, горнодобывающая промышленность.