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Relationship Between Occupational Risk and Personal Protective Equipment on the Example of Ferroalloy Production

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ABSTRACT

The objective of this work was to present the results of a comprehensive hygienic assessment of the occupational hazards in the ferroalloy production of a metallurgical plant. For the purpose of evaluating occupational hazards, we used data on the injury potential and occupational agents involved in working conditions, safety indicators for production facilities, occupational diseases, and the provision of workers with personal protective equipment. The assessment of occupational hazards demonstrated that for each of the occupations studied the occupational risk is equal to level 3, which means an average degree of risk. As a result of the research, the working conditions of the main occupational groups of the ferroalloy facility were evaluated as hazardous and injurious 3rd class of the 1st grade. After the intervention, it appeared that the workers were exposed to hazardous occupational noise. Acoustic equivalent levels at working places of the charge smelter, a crane operator, a senior melting operator, a furnace operator ranged from 85 to 87 dBA, which exceeds the maximum permissible level by 5-7 dB. Mathematical data processing showed that the distribution of noise in the working areas obeys a polynomial dependence. This paper provides recommendations on the implementation of a risk-oriented approach to the provision of personal protective equipment.

1. INTRODUCTION

Ferrous and nonferrous metallurgy along with ferroalloy production, in particular, are the significant industries of the Republic of Kazakhstan, representing about 18% of the country's industry. The development and application of advanced methods of assessment and management of occupational risks in steel industry become especially significant for Kazakhstan, given the considerable impact of the industry on the socio-economic development and quality of life in the regions.

In the context of current metallurgical industry, an essential challenge is to ensure safe working conditions. Achieving this is hardly possible without the analysis of occupational conditions at specific workplaces, health and work ability of personnel. Many researches made in recent years at metallurgical plants testify that working conditions were and keep being hazardous and injurious [1, 2]. Commonly, workers in metallurgical facilities are exposed to a complex of hazardous agents during all working hours: high noise level, dust and gas pollution [3]. To assess working conditions, it becomes necessary to take into account the combined influence of the above factors.

The noise is one of the most common negative health hazards for workers, its proportion of the main occupational hazards reaches 60%, and takes the 3rd place among the causes of occupational disease.

Further research demonstrates that workers who are under intensive noise exposure are at high risk of hearing loss [4]. Until hearing loss occurs, reactive anxiety increases, well-being deteriorates, and changes in the emotional-volitional sphere occur. The effect of noise on the body, considered from the perspective of chronic stress, leads to different symptoms - from functional cerebral disturbances of regulation to morphologically different pathology [5].

Lie et al. [6] systematically reviewed hearing impairment from noise exposure in a variety of industries. It has been confirmed that industrial noise exposure can increase the heart rate of workers [7]. It is impossible not to take into account the well-known fact that noise is one of the general biological stimuli of the central nervous system and the human body as a whole. Zeydabadi et al. [8] and Lee et al. [9] occupational noise has also been proven to affect cognitive functions (focus, response time, and recollection).

Particularly hazardous occupational conditions, including noise exposure, affect the development of occupational diseases and increase occupational risk. Occupational risk is considered [10] as a risk to the life or health of a worker associated with work activity. Occupational risk assessment is an evaluation of the health risk of injury from hazardous and noxious occupational factors and workload by the probability of health disorders, based on their intensity. The priority in determining the level of occupational risk is the assessment of a workplace environment.

Plenty of occupational risk assessment methods exist. Most of these methods are both standardized and described in the studies [11, 12]. Most often distinguished qualitative, quantitative, and hybrid methods [13]. One of the positively proven in practice is the Fine and Kinney method [14], the main idea of which is to assess the individual risks of an individual worker, defined as the likelihood of injury or illness because of an existing hazard.

Risk assessment is of vital concern for workplace welfare. Being a fundamental part of the European approach to occupational safety and health (OSH), risk assessment is a mandatory requirement for all workplace in European industries [15]. Key steps in risk assessment: 1. Hazard analysis by collecting and evaluating hazard-related information and the factors contributing to it 2. 2 Preparation of al required documentation for risk assessment. 3. Working closely with the employees during the occupational risk assessment. 4. Regular assessment of the occupational profiling in all workplaces. 5. Carrying out corrective measures. 6. Control and monitoring of the profiling management system.

Most notably, the above steps must be cyclical, and corrective action is required if indicators are unsatisfactory [16].

Integrated research of negative factors affecting workers and assessment of possible risks at an industrial facility is necessary to protect workers' health and create safe working conditions. So the purpose of research was to study working conditions, assess occupational risks, develop recommendations on their mitigation.

2. RESEARCH MATERIALS AND METHODS

Industrial company referred in this study is the «Taraz Metallurgical Plant» LLP (TMP) located in South Kazakhstan (42°55'59"N; 71°16'50"E). The company specializes in the production of ferrosilicomanganese, electrode and repair mass. The production technology is based on the reduction of ferromanganese compounds with carbon in electric furnaces at high temperatures, gas purification in bag filters, storage and transportation of ferrosilicomanganese.

These studies are based on the results of workplace assessment and hygienic evaluation of working conditions of the representatives of the core working professions in the ferroalloy workshop. To measure physical and chemical factors such as relative humidity, air temperature, airflow rate, concentrations of carbon monoxide, hydrogen sulfide and sulfur dioxide, as well as calculation of wet thermometer temperature and environmental heat load parameters we used instrument for control of air environment parameters, designed to measure working area air parameters, microclimate ("MES-200A") and Gas analyzer (GasAn-4). Noise measurements were recorded using an «Assistant» noise analyzer. The obtained data were compared with the established standards provided for by sanitary rules, hygienic standards approved in the manner determined by the state body in the field of sanitary and epidemiological welfare of the population in accordance with the Code of the Republic of Kazakhstan «On the health of the people and the healthcare system» [17].

To analyze the potentially hazardous agents in the researched workplaces, in which working conditions and agents are specific to the technological process and the plant have been selected.

The assessment of working conditions was carried out in accordance with the «Rules for occupational risk management» [18], which include a comprehensive assessment of working conditions for each profession (workplace) in the context of production (technological) processes and types of activities of the organization for compliance with their requirements of the legislation of the Republic Kazakhstan in the OSH, and consist of:

1) assessment of the harmfulness of working conditions (occupational hazards exposure);

2) assessment of injury hazard of working conditions (impact of hazardous production factors);

3) assessment of the safety of production equipment;

4) assessment of the availability of personal protective equipment (PPE);

5) occupational diseases.

According to the results of occupational risk assessment (ORA) for each profession (workplace), the degree of occupational hazards (OH) is set from one to five: 1st degree - acceptable risk; 2nd degree - low risk; 3rd degree - medium risk; 4th degree - high risk; 5th degree is a very high risk.

The degree of *OH* for each profession (workplace) was determined by the formula:

$$OH = 0.7 \cdot \frac{H + I}{2} + 0.2 \cdot \frac{Eqp + PPE}{2} + 0.1 \cdot D \quad (1)$$

where, *H* is an indicator of the hazardous of working conditions, characterizes the likelihood of the impact of production (harmful) factors on the work capacity of an employee of a given profession (professional group) at the workplace;

I - indicator of the injury risk of working conditions, characterizes the likelihood of the impact of production (dangerous) factors on the work capacity of an employee of a given profession (professional group) at the workplace;

Eqp - indicator of the safety of production equipment used in the labor process by an employee of this profession (professional group) at the workplace;

PPE - indicator of the availability of PPE used in the labor process by an employee of this profession (professional group);

D - indicator of diseases of workers of this profession (professional group).

Quantitative parameters given in formula (1) have the following values: 0.7 - 70% depend on harmfulness and injury danger of working conditions, 0.2 - 20% on safety of equipment and provision with PPE, 0.1 - 10% on health risks.

Classification of occupational conditions depending on the de facto level of occupational hazards was performed in accordance with the methodological recommendations «Hygienic criteria for assessing and classifying working conditions according to indicators of occupational hazards, severity and intensity of the working process» [19].

Advanced methods of research, including statistical, comparative and mathematical modeling methods, were used in the work to implement the specified objectives.

3. RESULTS AND DISCUSSION

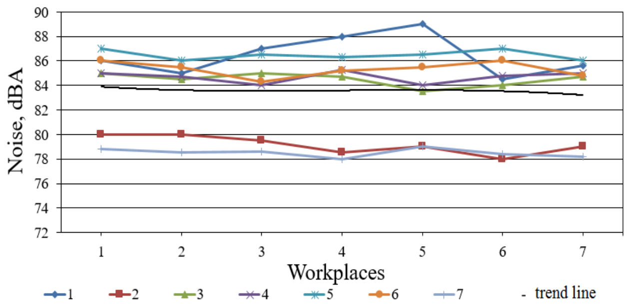
The analysis of the assessment of workplaces for labor conditions in the TMP demonstrated that the complex of OH at the workplaces: dust, toxic substances and noise have an effect on the workers of metallurgical production. Such gases as carbon oxide (II), aerosols of manganese oxide and iron, whose concentrations did not exceed the threshold limit value (TLV), were detected in the atmospheric air of the ferroalloy plant. Microclimatic conditions of the premises (indoor air temperature; speed of air circulation; relativity of air, etc.) also met the standards. Air mobility in workrooms is of great importance and affects the well-being of workers. Optimal air velocity of 0.2-0.3 m/s, and maximum 1.5 m/s in summer time is ensured in workplaces. This is achieved due to effective supply and exhaust ventilation, air conditioning, heat dissipation and heat emission control.

During the interventions in the production facilities excessive noise was detected (Figure 1). In terms of temporal characteristics, the noise is intermittent and broadband in spectrum. At the same time, sound levels at workplaces, as a rule, did not meet the standard parameters. This means that equivalent noise levels at the workplaces of a batcher, a smelter, a crane operator, a senior melting operator (furnace operator), and a furnace operator ranged from 85 dBA to 87 dBA, which exceeds the maximum permissible level (80 dBA) by 5-7 dB.

Mathematical processing of the results showed that the distribution of the noise level in the working area by profession obeys the dependence presented in Eq. (2) (Figure 1).

$$y=-0.0183x^3+0.2145x^2-0.7877x+84.486 \quad (2)$$

Parameter x is the actual noise figure in different points of 7 workplaces.



1 - a loader, 2 - an operator of the control panel, 3 - a melter, 4 - a crane operator, 5 - a senior melting operator, 6 - a hearth, 7 - an electric operator

Figure 1. Empirical dependence of the noise level in the working area by professions ($R^2 = 0.5801$)

The assessment of the injury risk of working conditions was carried out in accordance with the requirements of regulatory documents determining the content of the labor process, functional duties, types of work performed on hazardous production factors of mechanical impact for each of the professions represented in the ferroalloy facility, but we will dwell in more detail on the most common one.

The charge mixer is considered to be one of the essential workplaces in the ferroalloy plant; almost 40% of the workers are involved in this position. They are engaged in the following types of work: briquetting of finished products; control of the cooling process of finished products with the necessary supply of recycled water for irrigation; shipment of finished products to the warehouse; quality control of the briquette during the formation of the electrode mass through the molding machine; work on maintenance of the warehouse of finished products. At the same time, representatives of this professional group may be exposed to the following influences:

- fall in the work area, including:

1) fall of an employee from a height;

2) fall of an employee while moving (from one point to another);

3) falling, collapse of objects on the worker;

4) falling, destruction of buildings, structures and their elements.

Impact of production mechanisms, machines and parts of equipment, including:

1) the impact of moving and rotating parts of equipment, mechanisms, machines (impacts, seizures, squeezing);

2) exposure to structural elements of production equipment having sharp corners, edges, burrs and uneven surfaces, as well as exposure to high and low temperature of the surface of the equipment when the worker moves.

Electrical safety, fire and explosion safety, including:

1) electric shock;

2) threat of fire or explosion (friction or increased pressure), including those caused by electricity.

The total assessment of all the above indicators of injury risk was 155 points, which corresponds to the 3rd degree of risk of working conditions for a loader.

The safety assessment of production equipment was carried out for each profession at its workplace based on a comprehensive check for the availability of documentation for production equipment (availability of operating instructions, date of commissioning, service life, and verification certificates) and the availability of collective (individual) protection for the design of production equipment and its individual parts, ensuring the safety of work using production equipment.

The ferroalloy facility has the following equipment: an EM cart, a crane beam control panel, a circulating water pump, a belt conveyor, a rotary molding machine, a pressure gauge and a molding machine hopper; total of 7 items. The total score of the production equipment safety index was 17.5 points, which corresponds to the production equipment safety index (Eqp) equal to 3.

Checking the availability of personal and collective protective equipment for the design of production equipment and its individual parts was carried out based on visual inspection and technical control of the compliance of production equipment with the requirements established by regulatory and technical documentation, ensuring the safety of work using production equipment. The assessment of the provision of PPE was carried out for each profession for all types of PPE based on a comprehensive check of compliance with the requirements for the availability of regulatory and technical documentation for the issuance of PPE with an indication of the norm; the actual availability of PPE in accordance with the established norms for their issuance; the availability of quality certificates for the use of PPE (Table 1).

The total assessment of the indicator of the provision of PPE used in the labor process by an employee of the professional group of loaders was 22 points, which corresponds to an indicator of PPE equal to 2.

The assessment of the morbidity of workers was carried out based on a comprehensive check of sheets of temporary disability of workers in this profession according to the following three indicators: the total duration of temporary loss of disability (summation of all days of disability); number of cases of acute respiratory viral infections per year (direct count of existing cases of the disease with a given diagnosis); the presence of chronic diseases and conducting a survey.

Table 1. Assessment of the provision of PPE

Name of PPE	Issue rate for the year (unit)	Actual availability of PPE	Score
Cotton suit (jacket+trousers)	1 set for 12 months	available	2
Leather boots with hard toe cap	1 pair for 12 months	available	2
Protective helmet	1 piece for 36 months	available	2
Liner for the helmet	until wear	available	2
Respirator	1 piece for 1 shift	available	2
Cotton gloves	1 pair for 1 month	available	2
Anti-noise headphones	until wear	available	2
Underwear	1 set for 6 months	available	2
Polycarbonate goggles	until wear	available	2
Rubber boots	1 pair for 12 months	available	2
Jacket and trousers padded with cotton fabric	1 set for 36 months	available	2
Boots with a rubber bottom or leather boots with a hard toe cap	1 pair for 24 months	available	2
Sum of points			22
Number of PPE			11
PPE supply indicator, total			2

Table 2. Evaluation of the OH at the ferroalloy facility

Profession	Amount of workers	H	I	Eqp	PPE	M	D
A shifter	35	**3**	**3**	**3**	**2**	**3**	**3**
Control panel operator	8	**3**	**3**	**3**	**2**	**3**	**3**
A melter	8	**3**	**4**	**3**	**2**	**3**	**3**
Crane operator	10	**3**	**3**	**3**	**2**	**3**	**3**
Senior melting operator	5	**3**	**3**	**3**	**2**	**3**	**3**
Blast furnace worker	20	**3**	**4**	**3**	**2**	**3**	**3**
Electrode operator	5	**3**	**3**	**3**	**2**	**2**	**3**

Analysis of the data showed that chronic diseases such as diseases of the bronchopulmonary system, the musculoskeletal system, the genitourinary system, as well as hypertension predominate among workers in the batching profession. In the questionnaires, the workers noted rapid fatigue, irritability and decreased concentration. There have also been cases of injuries associated with negligence and non-compliance with safety regulations with mechanical equipment.

Thus, the analysis of occupational pathology data showed that the noise factor has an impact on the development of occupational morbidity. This is confirmed by the frequency of occurrence of diseases of the circulatory and cardiovascular systems, as well as an increase in injuries.

The total score of the morbidity rate (M) was 133 points, which corresponds to an indicator of 3. Results of the calculation of the assessment of occupational risks are presented in Table 2.

When making calculations, data on the risk of injury and hazardous of working conditions, safety indicators of production equipment, morbidity rates of workers and their availability with personal protective equipment were used. Occupational risk assessment showed that for each of the studied professions, the production risk is 3, which means the average level of risk - class of working conditions is 3.1.

Psychophysiological risks of TMP workers were identified and assessed according to the current Methodical Recommendations [19]. Assessment of psychophysiological risks, of which both labor process severity and labor process tenseness scored 1 point each, which corresponds to the second class of working conditions.

According to the norms approved in the Republic of Kazakhstan for issuing special clothing and other personal protective equipment (PPE), employees of organizations for a number of professions of the ferroalloy facility do not provide PPE against noise [20]. In accordance with the excesses of permissible noise pollution levels identified during the certification, it is proposed to use PPE for the organ of hearing that reduces by at least 20 dBA, for example, earmuffs, for working conditions class of 3.1. When protecting the hearing organ, it is necessary to use protective equipment - earplugs, anti-noise helmets, noise-insulating suits, which must correspond to the actual noise parameters in accordance with the requirements of the Technical Regulations [21].

4. CONCLUSIONS

This paper is aimed at the analysis of labor conditions of workers in the ferroalloy industry of TMP. Within the certification of workplaces, the working conditions of the leading specialty workers involved in the ferroalloys process were investigated.

The research demonstrated that the noise exposure levels at the workplaces (charge-blender, smelter, crane operator, senior melting apparatus operator, mine operator) did not comply with the regulatory requirements, which exceeded the maximum permissible level by 5-9 dB. The occupational risk assessment found that for each of the examined professions the occupational risk is equal to 3, which means the average risk level - working conditions class 3.1.

Use of smart, advanced PPE is recommended to improve working conditions of TMP employees considering risk-oriented approach. Considering ergonomic features, the application of personal protective equipment is one of the measures to prevent adverse effects of hazardous and harmful production factors on workers. While choosing PPE it is necessary to take into account specific conditions of production process, type and duration of employees' exposure to hazards, as well as their individual preferences. Only the correct use of PPE can provide the maximum protective effect from their use in the workplace. The effectiveness of the use of PPE is determined by the following basic requirements: the correct choice of a specific brand of PPE, maintaining PPE in good condition, training of personnel in the rules for using PPE in accordance with the operating instructions throughout the entire period of their use.

The effectiveness of all PPE must be confirmed by certificates of conformity or declaration, maintaining a normal functional state and performance. Establishing a clear link with the results of the occupational risk assessment will ensure the risk-oriented mechanisms for issuing personal protective equipment, which are the main measures of safe work recommended for implementation in Kazakhstan.

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