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Safe Work and Personal Protective Equipment in an Economic Context

Sholpan Abikenova[1], Elmira Kulmagambetova[2], Gulzhan Daumova[3*], Nazgul Abdrakhmanova[2]

[1] National Confederation of Employers «Paryz», Astana 010000, Kazakhstan
[2] Republican Research Institute for Occupational Safety and Health, Astana 010000, Kazakhstan
[3] East Kazakhstan regional Branch of the Republican Research Institute for Occupational Safety and Health, Ust-Kamenogorsk 070018, Kazakhstan

Corresponding Author Email: Gulzhan.daumova@mail.ru

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ABSTRACT

The article explores the economic context of ensuring safe work and the selection of personal protective equipment (PPE) based on the dust factor. Taking into account measurements of production factors at workplaces, using the example of ferroalloy production at the Taraz Metallurgical Plant (Republic of Kazakhstan), it has been determined that the levels of general industrial dust found at certain workplaces (crusher operator, raw material reception and crushing section supervisor, charger, miner, smelter, senior master of the sinter preparation department) significantly exceed the established norms of 4 mg/m³. As a result of the research, the working conditions of the main occupational groups in ferroalloy production are assessed as harmful and hazardous - Class 3, Degree I. Recommendations are provided for the implementation of a risk-oriented approach in ensuring personal protective equipment, as well as the application of a different mechanism for determining the insurance tariff rate based on the class of professional risk, determined by the type of economic activity. This takes into account a new integrated differentiated indicator - professional risk at each workplace.

1. INTRODUCTION

The ILO's global strategy defines the role of international labor standards as a primary foundation for advancing occupational safety and calls for comprehensive actions [1]. The program aims to provide scientific justification for state policies aimed at strengthening the role of insurance mechanisms in preventing workplace accidents and occupational diseases. The mechanism (program) of insurance against workplace accidents and occupational diseases is the most common and strategically significant type of social security in many countries. Its constituent elements include medical services, professional rehabilitation, and benefits for injured workers or family members of the deceased (in the event of the breadwinner's loss). Recent trends in the development of insurance programs highlight the relevance of preventive measures to incentivize the improvement of working conditions and occupational safety. This includes active support and funding for informational-educational and preventive initiatives.

The results of scientific research serve as the basis for the implementation in Kazakhstan of economic stimulus tools aimed at improving working conditions and occupational safety through the reform of the Mandatory Occupational Accident Insurance System. Specifically, the application of a different mechanism to determine the size of the insurance tariff based on the class of professional risk, determined by the type of economic activity, taking into account a new integrated differentiated indicator - professional risk at each workplace.

Methods of economic incentives for employers to improve working conditions have a significant positive impact on labor productivity, labor competitiveness, quality index, and production rates. Therefore, we have studied production areas and workplaces in metallurgical enterprises, particularly ferroalloy plants, which fall into the category of the most hazardous in terms of ensuring safe working conditions.

According to the initial joint assessment of the burden of diseases and injuries related to occupational activities, compiled by the World Health Organization and the International Labour Organization, in 2023, a total of approximately 2.3 million deaths and 90 million disability-adjusted life years worldwide were associated with 41 pairs of occupational risk factors and health outcomes [2]. Globally, approximately 340 million workplace accidents and 160 million victims of occupational diseases are registered annually. The dynamics in the Republic of Kazakhstan illustrate an increase in the number of workplace accidents and a deterioration in the health of the working population [3].

Modern ferroalloy production is closely monitored by healthcare specialists due to the impossibility of eliminating the adverse impact of production factors on the workers' bodies. A comprehensive assessment of the occupational risk to the health of workers in ferroalloy production is crucial, including the identification of occupational risk groups and a predictive assessment of the development of occupational and work-related diseases.

The production of ferroalloys is classified as a harmful and hazardous industry. In ferroalloy production facilities, working conditions, the pronounced industry specificity, the complexity and diversity of technological processes, and the peculiarities of equipment operation are associated with a certain level of danger for the workers. Employees performing technological operations and executing labor functions may be simultaneously exposed to various types of hazards, occupational injuries, and work-related diseases.

For example, Dendup et al. [4], an analysis of accidents in ferroalloy production is presented. The authors identified characteristics of workplace injuries, the accident frequency rate, the severity level of accidents, and the main causes in six ferroalloy sectors in Bhutan's industrial landscape. This study demonstrated that the accident frequency rate alone cannot be used as the sole indicator for predicting the occurrence of hazardous factors in the workplace. The primary causes of accidents in ferroalloy production were identified, such as the impact of moving, flying, rotating objects and parts (44.2%), falls from height (20.9%), and exposure to extreme temperatures (26.7%).

The characteristics of technological processes in metallurgy, including those in ferroalloy production, do not allow for the complete elimination of the impact of harmful industrial factors on the workers' health and well-being.

The creation of unfavorable factors in the work environment was attributed to the technological process, equipment operation, and the effectiveness level of collective protection systems.

In the technology of ferroalloy production, high concentrations of dust and harmful gases are emitted at various stages of the technological process. During the metal smelting process, dangerous and intense emissions are formed. The chemical composition of the dust and emitted gases, as well as the release of pollutants, varies and depends on the composition of the metal charge, its degree of contamination, furnace lining condition, smelting technology, and the choice of energy carriers.

The dust factor in modern metallurgical enterprises, due to the specifics of the ferroalloy production technological process, is one of the leading factors.

One of the harmful occupational factors is dust, which leads to occupational diseases (silicosis, dust bronchitis) [5, 6].

Dust in the workplaces of ferroalloy production mainly contains manganese, silicon dioxide, and other accompanying elements.

Experts believe that the presence of dust in the air with particles smaller than 10 micrometers increases the risk of occupational diseases, such as pneumoconiosis (silicosis) and bronchitis, due to the low settling rate of dust and its prolonged presence in the work zone air. Fine-dispersed dust and dust particles smaller than 10 micrometers pose additional challenges for dust capture. Particular danger is posed by respirable particles (up to 5 micrometers in diameter) and subbronchial particles (with diameters ranging from 5 to 10 micrometers) [7].

Myklebust et al. [8] have determined that in metallurgical plants producing silicon and silicomanganese alloys, the level of dust can be substantial. Dust is formed both mechanically, through the generation of fine particles when handling raw materials, and thermally, through the reduction and oxidation of raw materials and products. Thermally generated SiMn vapors, which form during the oxidation of liquid (Si) and vaporizing (Mn) metals, consist mainly of Si, Mn, and O, forming various complex oxides. Secondary elements include Mg, Ca, Al, and K, while trace elements include Na, Fe, Zn, Cu, and Cl.

Langard [9], respiratory symptoms, lung function, and the prevalence of generalized obstructive lung diseases among workers engaged in the production of ferrochrome and ferrosilicon were investigated. The author identified that the studied diseases are associated with a high level of general dust, particularly due to the exposure to dust containing amorphous silica.

Merget et al. [10] have identified health hazards associated with the inhalation of amorphous silica. Occupational exposure to crystalline silica dust is linked to an increased risk of pulmonary diseases, such as silicosis, tuberculosis, chronic bronchitis, chronic obstructive pulmonary disease, and lung cancer.

Similarly, other authors have identified occupational diseases resulting from the exposure to amorphous silica in the ferroalloy industry [11].

Kjuus et al. [12] studied overall mortality and cancer incidence among workers from six of the oldest ferrosilicon and ferromanganese plants in Norway. The study included 6,494 men who had worked for more than 18 months until 1970, and they were followed from 1953 to 1982. An elevated incidence of lung cancer (SIR=1.75) and prostate cancer (SIR=1.56) was detected among workers from one ferrosilicon plant, and colorectal cancer (SIR=1.90) was observed at another ferrosilicon plant.

In continuation of the aforementioned analysis, by Hobbesland et al. [13], mortality from non-malignant respiratory diseases among male workers in Norwegian ferroalloy plants was studied. Their statistics included 14,730 individuals, first employed between 1933 and 1990, and who worked for at least 6 months at one of the 12 plants. The duration of work in specific workshops and exposure to amorphous silica in ferrosilicon/silicon-metal production enterprises (FeSi/Si-met), assessed through a workplace matrix, were the main exposure variables. Deaths were observed during 1962-1990. According to the authors, the overall mortality from non-malignant respiratory diseases did not increase, but mortality from bronchitis, emphysema, and asthma combined was significantly higher among men who worked for at least 3 years (16 deaths). Poisson regression analysis of mortality indicated a significant increase of 0.06 per unit of amorphous silica exposure 10-20 years after exposure. The increased mortality of workers from bronchitis, emphysema, and asthma is linked to prior exposure to amorphous silica. The authors also established a link between worker mortality from pneumonia and manganese exposure.

The majority of studies focusing on assessing the impact of occupational factors on the health of workers in ferroalloy production not only contain information about levels and duration of exposure [14] but also provide an assessment of the risk of developing cancer among workers [15], an evaluation of mortality rates and structure [16], an assessment of the prevalence and severity of chronic obstructive pulmonary disease [17], and changes in lung function [18].

Indeed, a study on the impact of ultrafine dust particles on workers in ferroalloy production revealed that the elemental composition and particle structure at different stages of production are not uniform. Measurements of particle size distribution provide important information about the impact of ultrafine particles, which may not be evident in measurements of mass concentrations [19].

Bala and Tabaku [17] concluded that the prevalence of lung disease and its symptoms are high among workers, and there is a clearly established correlation between air pollution in the workplace and chronic obstructive pulmonary disease (COPD).

The conclusion about a significant correlation between lung function and the impact of dust on them was drawn by researchers who studied the relationship between annual changes in lung function and the impact of occupational dust on workers at ferroalloy plants. This was based on the results of periodic medical examinations, which included annual spirometry and a respiratory questionnaire [20].

Scientific research has shown that the combination of negative factors contributes to the increase in occupational diseases among employees of enterprises. In a subsequent study, the hygienic characteristics of working conditions and their impact on the health of workers employed in ferroalloy production were examined. The authors found that the particle size distribution and concentration of dust directly influence the development of respiratory organ pathology [21].

Therefore, the assessment of the impact on health of general industrial dust present in the workplace air has been and remains a relevant issue. In connection with this, the aim of the research was to study working conditions, develop recommendations for their improvement through the selection of new personal protective equipment, and consider insurance based on a new integrated differentiated indicator - the professional risk at each workplace.

2. OBJECT AND METHODS OF RESEARCH

The Taraz Metallurgical Plant is a metallurgical enterprise in Kazakhstan that produces ferrosilicomanganese, electrode paste, cold ramming carbon mass, repair mass, enriched microelement superphosphate in powder form, electrically calcined anthracite, and slag aggregate.

Additionally, LLP «Taraz Metallurgical Plant» provides services for processing phosphorite fines, manufacturing and installing custom equipment, and has a fleet of specialized vehicles.

Currently, LLP «Taraz Metallurgical Plant» is one of the most significant system-forming enterprises in the metallurgical industry of Kazakhstan.

The plant has a ready infrastructure that allows for the installation of metallurgical furnaces with a combined production capacity of up to 400,000 tons of manganese ferroalloys per year.

The production of ferroalloys involves the reduction of ferromanganese compounds by carbon in electric furnaces at high temperatures, gas cleaning in bag filters, and the storage and transportation of ferrosilicomanganese.

Ferrosilicomanganese (FeSiMn) according to GOST 4756-91 (ISO 5447-80) is an alloy of manganese, silicon, and iron, obtained by reducing manganese-containing raw materials and quartzite with the help of carbon from coke and coal. Ferrosilicomanganese is used in the iron and steel industry for the production of steel and cast iron as a deoxidizer and alloying additive. It imparts wear resistance, impact resistance, and heat resistance to the alloy, reduces the solubility of sulfur and oxygen in the molten metal, and allows for the desired metal structure during crystallization.

Manganese concentrates are used in the iron and steel industry for the production of cast iron, steel, and ferroalloys. Manganese-alloyed steel exhibits high strength characteristics. Working parts of crushing machines, ball mills, railway tracks, and other metal products subjected to high wear are typically made from such steel.

The ferroalloy production includes the following components:

- Ferroalloy workshop;
- Raw material preparation department;
- Raw material receiving and crushing area/Charging area;
- Melting department;
- Water treatment and cooling tower area;
- Gas cleaning area;
- Finished product department;
- Metal pouring department;
- Power service;
- Mechanical service.

The total number of employees in ferroalloy production is 78 people.

The primary raw material for ferrosilicomanganese production is manganese concentrate, obtained through the enrichment of manganese ore. The quality of manganese concentrates is assessed based on the content of manganese, iron, silicon oxides, calcium, phosphorus, sulfur, and the particle size distribution of the concentrates.

The analysis of air samples for dust content was performed using an inductively coupled plasma mass spectrometer Agilent 7500cx (USA).

The elemental composition of ferroalloy dust is shown in Table 1.

Table 1. Elemental composition of ferroalloy dust

Mn, %	SiO_2, %	Al_2O_3, %	CaO, %	MgO, %	Fe^{3+}, %	P, %
22.78	32.11	0.52	7.92	2.48	0.91	0.04

The primary harmful occupational factor in production is the air contamination in the work zone with dust of a complex chemical composition. The main components of the aerosol are manganese and amorphous silicon dioxide in the form of condensation aerosol with a content ranging from 20 to 40%, emitted during the melting and pouring of metal.

According to the results of the certification of production facilities according to the conditions, a universal gas analyzer Gank-4 was used during measurements of general industrial dust.

Air samples from the work area were collected in accordance with GOST R 12.1.005-88 [22]. When determining the dust content, approximately 500 dm^3 of air was sampled at a rate of 50 L/min for 10–15 minutes. Air sampling was conducted at workplaces during working hours on the premises of the ferroalloy production facility.

Previously, it was established by the authors that at the Taraz Metallurgical Plant, workers are exposed to a complex of hazardous environmental factors such as dust, toxic substances, and noise [23].

During the research, it was found that the noise levels at workplaces (chargers, smelters, crane operators, senior melting operators, and furnace operators) did not comply with regulatory values, exceeding the permissible level by 5-9 dB. The assessment of occupational risk showed that for each of the investigated professions, the production risk was rated as 3, indicating a moderate risk level - labor conditions class 3.1

[23].

This article is a continuation of the aforementioned study, focusing on the impact of general industrial dust specifically in ferroalloy production.

Modern methods of scientific research, including statistical and comparative ones, are used to implement the tasks set in the work.

3. RESULTS AND DISCUSSION

The analysis of workplace assessment for working conditions revealed that in the ferroalloy production, there was an excess of general industrial dust (Table 2). In this case, the dust concentration at the workplaces did not comply with the regulatory parameters. The actual concentrations of general industrial dust at the workplaces of crushers, the master of the raw material receiving and crushing area, chargers, furnace operators, melters, and the senior master of the raw material preparation section ranged from 4.5 mg/m³ to 5.88 mg/m³, exceeding the permissible exposure limit (4 mg/m³) by 0.5 to 1.88 mg/m³.

The following Table 3 shows the assessment of morbidity by professions of ferroalloy production.

Based on the analysis of illnesses (Table 3), it can be concluded that crushers and chargemen are more susceptible to upper respiratory tract infections due to the exposure to elevated levels of general industrial dust.

According to hygiene criteria for the mentioned workplaces, the work conditions have been classified as category 3.1.

Table 2. Measurement results of general industrial dust at ferroalloy production workplaces

No.	Name of Profession	Actual Dust Level, General Industrial, mg/m³
	«Ferroalloy» Department	
1	Chief Engineer for Finished Products, Consumables, and Raw Materials	4.8
2	Deputy Head of Department for Technology	4.9
3	Cleaner of Administrative and Production Premises	4.6
4	Deputy Head of Department for Production	4.6
5	Senior Master of the Melting Division	4.8
6	Mechanic of the «Ferroalloy» Department	4.9
7	Energy Specialist of the «Ferroalloy» Department	4.9
8	Head of the «Ferroalloy» Department	4.7
9	Senior Master of I&C (Instrumentation and Control)	4.8
	Charge Preparation Department	
10	Master of the Raw Material Receiving and Crushing Area	5.61
11	Senior Master of the Raw Material Preparation Section	5.61
12	Master of the Section	5.61
	Raw Material Receiving and Crushing Section / Charging Section	
13	Wagon Tippler Operator	5.39
14	Charger	5.2
15	Control Panel Operator	5.2
	Smelting Division	
16	Shift Supervisor	5.37
17	Charge Mixer	5.9
18	Control Panel Operator	4.5
19	Smelter	4.5
20	Crane Operator	4.0
21	Senior Melting Technician (Furnace Operator)	5.0
22	Furnace Operator	5.2
23	Electrode Technician	4.7
	Water Treatment and Cooling Towe Section	
24	Pump Unit Operator	5.2
	Gas Cleaning Section	
25	Dust and Gas Capture System Operator	5.39
	Finished Product Department	
26	Crusher Operator	5.78
27	Senior Master of Finished Product Department	5.28
28	Packer (Packaging Operator)	4.51
29	Forklift Driver	4.51
	Metal Pouring Department	
30	Metal Pourer (Caster),	4.9
31	Refractory Worker (Ladle Lining Specialist)	5.39
32	Ferroalloy Breaker	5.4
33	Crane Operator	4.0
34	Senior Master of Metal Pouring Department	4.91
	Power Engineering Department	
35	Electrical Equipment Repair and Maintenance Electrician	4.52
36	Electrical Equipment Repair Master	4.20
	Mechanical Services	
37	Electrogas Welder	4.89
38	Locksmith - Repairman	4.84
39	Master of Technological Equipment Repair	4.31
40	Locksmith for Repair and Maintenance of Lifting Mechanisms	4.89

Table 3. Morbidity assessment by professions

No.	Types of Diseases	Types of Professions				
		Crusher Operator	**Charge Mixer**	**Smelter**	**Furnace Operator**	**Electrode Worker**
1	Acute Infections of Multiple Locations of the Upper Respiratory Tract	4	3		2	
2	Acute Upper Respiratory Tract Infection	7	5	1	4	
3	Acute Bronchitis	2	1	3	1	
4	Acute Bronchitis due to Other Specified Organisms				2	
5	Mucopurulent Chronic Bronchitis	2	1			
6	Acute Pharyngitis	4	3	1	3	
7	Acute Pharyngitis due to Other Specified Organisms	2	1		3	
8	Acute Tonsillitis	4	3		1	1
9	Acute Respiratory Viral Infection	22	18		4	1
10	Acute Maxillary Sinusitis			2		
11	Acute Tracheitis	1				
12	Myelodysplastic Syndrome, Hematology and Oncology	2	1			

Table 4. Comparative analysis of the provision of PPE crusher and charge maker

No.	Name of the Profession	Name of the PPE
1	Crusher Operator	PPE according to standard standards (actually issued) 1. Suit (jacket + trousers) made of cotton fabric 2. Leather boots with a rigid toe cap 3. Protective helmet 4. Balaclava for helmet 5. Gloves made of cotton fabric 6. Polycarbonate safety goggles 7. Respirator 8. Noise-canceling headphones 9. Underwear During the winter period: 10. Insulated suit (jacket + trousers) made of cotton fabric
	A factor from which protection is not provided: Exposure to dust (chemical) the factor	PPE according to the nomenclature for teratogenic substances (cause birth defects) 11. Full-face mask, Protection class respirator FFP3 [24]; 12. Chemical suit of spacesuit type [25]; 13. Chemically resistant protective gloves [26]
2	Charge Mixer	1. Suit (jacket + trousers) made of cotton fabric 2. Leather boots with a rigid toe cap 3. Protective helmet 4. Balaclava for helmet 5. Respirator 6. Gloves made of cotton fabric 7. Noise-canceling headphones (on-duty) 8. Underwear 9. Polycarbonate safety goggles (on-duty) During the winter period: 10. Insulated suit (jacket + trousers) made of cotton fabric
	A factor from which protection is not provided: Exposure to dust (chemical) the factor	11. Full-face mask, protection class respirator FFP3 [24]; 12. Chemical suit of spacesuit type [25]; 13. Chemically resistant protective gloves [26]

In order to reduce the risk of health disorders caused by exposure to industrial dust, workers in ferroalloy production should be provided with properly selected respiratory protection equipment.

Table 4 provides a comparative analysis of personal protective equipment provision using the example of a «Crusher Operator and Charge Mixer» positions.

Table 4 presents the standard regulatory list of personal protective equipment (PPE) for this profession according to the cross-industry typical norms [27], as well as according to the new approach in accordance with the PPE nomenclature developed by the Republican Scientific Research Institute for Occupational Safety of the Ministry of Labor and Social Protection of the Population of the Republic of Kazakhstan [28].

The analysis of working conditions at the enterprise revealed that:

- There is a significant deviation from the established insurance tariff based on the Occupational Risk Level (ORL) determined by the State Classification of Economic Activities (SCEA), with the actual ORL for professional categories and job positions.

- There are differences in actual working conditions and, consequently, the ORL at enterprises within the same industry, i.e., with identical ORL for specific job positions/professions.

Thus, the obtained primary data confirms the scientific hypothesis about the necessity of introducing a new classification of occupational risks to justify the calculations of insurance tariffs in the occupational safety and health system.

The degree of occupational risk at enterprises within the same industry, for similar professions, exhibits differences that justify the introduction of a new classification of occupational risk. The obtained results provide grounds to state:

- The current practice of determining insurance tariff based on the State Classification of Economic Activities (SCEA) does not reflect the actual financial responsibility of the employer based on the real level of individual production risk of a specific production facility, including the connection with occupational risk for each specific profession or working conditions of insured employees.
- There is a high dependence on the results of the Occupational Risk Assessment (ORA) on subjective expert judgment.
- There is a lack of a mechanism for quality control of the occupational risk assessment.

4. CONCLUSIONS

The study is dedicated to the analysis of working conditions for the employees of the ferroalloy production at «Taraz Metallurgical Plant» LLP, particularly focusing on the dust factor. During the research, it was identified that the concentration of general industrial dust at the workplaces of the crusher operator, raw material receiving and crushing section supervisor, charging operator, furnace operator, smelter, and senior master of the raw material preparation department ranged from 4.5 mg/m³ to 5.88 mg/m³, exceeding the permissible exposure limit (4 mg/m³) by 0.5-1.88 mg/m³.

Due to the elevated air particulate levels in the work zone, it is recommended to use a full-face mask with a respiratory protection class of FFP3 instead of a regular protective mask.

Thus, using the example of one of the most common professions in ferroalloy production, the effectiveness of the newly developed approach is demonstrated. This once again confirms that timely and adequate provision of personal protective equipment, taking into account occupational risks, is an important aspect of preserving human resources and ensuring workplace safety.

As proposals, one can consider:

- The need for modernizing the methodology of assessing occupational risk by transitioning to an integrated assessment of occupational risk for the entire enterprise based on the occupational risk at each workplace.
- Expanding the list of assessment criteria for occupational risks, including the frequency of occupational injuries (relative to the number of workplaces), the presence, completeness, existence of a training system, and certification procedures for the Occupational Safety and Health (OSH) service, etc.
- Establishing a mandatory minimum of indicators for assessing production factors when identifying occupational risk for each specific profession (position, workplace).
- Implementing quality control of occupational risk assessment:
- Based on the formalized establishment of requirements for specialized organizations to have certified OSH experts (authorized to conduct occupational risk assessments).
- Through quality control of training specialists (experts) in the field of OSH.

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