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АНАЛИЗ СОВРЕМЕННОГО СОСТОЯНИЯ ШЛАКООТВАЛОВ ГОРНО-МЕТАЛЛУРГИЧЕСКОГО СЕКТОРА ТОО «КОРПОРАЦИЯ КАЗАХМЫС» И ИХ ВОЗДЕЙСТВИЕ НА ОКРУЖАЮЩУЮ СРЕДУ

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Аннотация: Приведены исследования по накоплению отходов промышленности, в частности горно-металлургической. Проблемы и вызовы накопления и переработки отходов горно-металлургической промышленности. Приведена характеристика отвалов медеплавильного шлака по данным Комитета статистики за 2023 г. Изучен состав отвалов шлака, рассмотрено влияние отвалов шлака на окружающую среду. Изучен химический состав отвалов шлака Балхашского медеплавильного завода и рассмотрены связанные с ними экологические риски. Рассмотрено негативное антропогенное влияние отвалов шлака на атмосферу, почвы, водоемы. Проведённые исследования позволили разработать комплекс природоохранных мероприятий, направленных на минимизацию негативного влияния шлакоотвалов на окружающую среду. В ходе работы были определены приоритетные направления по снижению антропогенной нагрузки от накопленных горно-металлургических отходов. Выявленные данные свидетельствуют о необходимости перехода к комплексной системе управления шлаковыми отвалами, сочетающей современные методы переработки с принципами устойчивого развития. Особое значение приобретает создание замкнутых технологических циклов, позволяющих минимизировать экологический ущерб при максимальном ресурсосбережении.

Ключевые слова: отходы горно-металлургического сектора, отвалы шлаков, тяжелые металлы, воздействие на окружающую среду, защита и охрана окружающей среды, техносферная безопасность.

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Analysis of the current state of the slag dumps in the mining and metallurgical sector of «Kazakhmys Corporation» LLP and its impact on the environment

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Abstract: This article presents research on the accumulation of industrial waste, in particular mining and metallurgical waste. Problems and challenges of accumulation and processing of waste from the mining and metallurgical industry. The characteristics of copper smelting slag dumps according to the data of the Statistics Committee for 2023 are given. The composition of slag heaps has been studied, and the impact of slag heaps on the environment has been considered. The environmental risks associated with slag heaps have been studied and considered. The negative anthropogenic impact of slag dumps of the Balkhash copper smelter and its chemical composition on atmospheric pollution is considered. soils, reservoirs. The conducted research has made it possible to develop a set of environmental protection measures aimed at minimizing the negative impact of slag heaps on the environment. In the course of the work, priority areas were identified to reduce the anthropogenic load from accumulated mining and metallurgical waste. The revealed data indicate the need to switch to an integrated slag dump management system that combines modern processing methods with the principles of sustainable development. Of particular importance is the creation of closed technological cycles that minimize environmental damage while maximizing resource conservation.

Key words: waste from the mining and metallurgical sector, slag dump, heavy metals, environmental impact, environmental protection and protection, technosphere safety.

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Introduction

Kazakhstan, occupying the 9th place in the world in terms of territory and possessing enormous reserves of mineral resources [1—3], faces serious environmental challenges associated with the formation and accumulation of industrial waste from a number of industries, such as mining [4—6], metallurgy [7—9], energy [10—12], chemical [13—15], construction [16—18], etc. According to official data from the Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan (MEGNR RK), as of 2023, according to the State of the Environment report, the total amount of accumulated industrial waste in the country exceeded 35 billion tons, which is about 15% of all waste generated over the entire period of industrial development of the state. The dynamics of waste accumulation in Kazakhstan for 2010—2023 according to the MPR RK is presented in Table 1.

Table 1

Dynamics of waste accumulation in Kazakhstan
Динамика накопления отходов в Казахстане

Years	Total waste volume (billion tons)	Share of industrial waste (%)
2010	25	88
2015	29	89
2020	32	91
2023	35	92

Of particular concern is the structure of the waste generated, according to the state report "On the state of the Environment of the Republic of Kazakhstan" for 2022 and the analysis of statistical data, which show that the vast majority — about 90% of the total volume — is accounted for by enterprises of the mining and metallurgical complex [19—21]. This disparity is explained by the specifics of Kazakhstan's economy, where mining and processing industries traditionally occupy a leading place in the industrial sector [22—24].

The main sources of industrial waste in Kazakhstan:

1. The mining and metallurgical complex is the largest waste generator, including:

• Tailing dumps of processing plants (about 500 million tons are formed annually);

• Metallurgical slags (over 50 million tons per year);

• Ash and slag waste (more than 10 million tons annually);

• Overburden and host rocks (up to 1 billion tons per year).

The energy sector, where the main types of waste are:

• Ash and slag from thermal power plants (about 8 million tons per year);

• Oil sludge (over 200 thousand tons annually);

• Spent catalysts and adsorbents.

2. Chemical and petrochemical industry, producing:

• Oil refining waste (over 1 million tons per year)

• Phosphogypsum (about 3 million tons annually);

• Waste from the production of mineral fertilizers;

• Polymer waste and chemical reagents.

It should be noted that the problem is aggravated by the uneven territorial distribution of waste. More than 60% of all industrial waste is concentrated in three regions: Karaganda, Pavlodar and East Kazakhstan regions, where the country's largest mining, metallurgical and energy enterprises are located.

The so-called "historical waste", accumulated over decades of industrial development, is particularly dangerous. According to experts, only 10—15% of the total waste is processed or disposed of, the rest accumulates in special landfills and storage facilities, many of which do not meet modern environmental standards (Waste Management in Kazakhstan: Current Status and Challenges. World Bank Research, 2020, Washington, pp. 67–72.) [25—26].

Thus, based on the above analysis, the purpose of these studies is the need to develop a number of recommendations to reduce the anthropogenic environmental impact of man-made waste from the mining and metallurgical industry and converter slag dumps of «Kazakhmys» LLP.

Results and discussion

The problem of industrial waste generation in the Republic of Kazakhstan and the Karaganda region

In the structure of industrial production in Kazakhstan, the Karaganda region occupies a special position, being not only the historical center of the country's industrial development, but also the main generator of industrial waste. According to Kazhydromet data for 2022, this region accounts for about 30% of the total volume of industrial waste generated in the Republic of Kazakhstan. This figure becomes even more significant when we consider that with an area of only 428,000 km^2 (less than 16% of the country's territory), the region concentrates about 40% of the state's industrial potential.

One of the key waste-forming enterprises in the region is Kazakhmys LLP. Kazakhmys LLP is a leading copper producer in the region, whose activities are

accompanied by the formation of waste slag from copper smelting, the accumulated volume of which today exceeds 32 million tons.

The problem is compounded by the fact that a significant part of this waste (according to various estimates, from 60% to 75%) belongs to hazard classes III — IV, which requires special storage and disposal conditions. Environmentalists are particularly concerned about:

• Open slag dumps exposed to wind erosion;

• Pollution of groundwater and surface waters;

• Land degradation of industrial and adjacent areas.

According to the research of a team of scientists from Kazakhstani universities [27 — 29], the concentration of some heavy metals in the soils of the industrial zone exceeds the maximum permissible concentration by tens of times:

• Copper — up to 25 MPC;

• Lead — up to 18 MPC;

• Zinc — up to 12 MPC.

This situation requires immediate measures to:

1. Introduction of waste recycling technologies;

2. Reclamation of disturbed lands;

3. Improvement of the environmental monitoring system.

Special attention should be paid to the development of a comprehensive program to reduce the environmental burden, including both technical and organizational measures with the active participation of all stakeholders — from industrial enterprises to local government agencies, scientific and business communities. According to the Committee for Environmental Regulation of the Karaganda region, in particular, in the city of Balkhash in 2023, it amounted to 450 million tons. (Table 2).

The city of Balkhash occupies a special place in the list of territories of Kazakhstan with the most difficult ecological situation. This status is due to the long-term intensive activity of the two largest industrial facilities — the Balkhash Copper Plant (BCP) and the associated mining and processing plant. According to the environmental monitoring data of the Republic of Kazakhstan for 2023, the level of environmental pollution in this region is 4 — 7 times higher than the national average.

The Balkhash Copper Plant, which is part of the Kazakhmys Corporation LLP, traces its history back to 1938. Over its almost century-long history, the company has become one of the key elements of the copper industry not only in Kazakhstan, but throughout Central Asia. The basis of the production process is the pyrometallurgical processing of copper concentrates, which is accompanied by the formation of a significant number of by-products, including slags.

The technological cycle of slag formation at the BCP is a complex multi-stage system:

1. Melting stage in reflective furnaces:

• Temperature range: 1200 — 1300 °C;

• Use of fluxes (silica sio_2, lime CaO);

• Process duration: 12 — 18 hours;

• Formation of primary slag melt.

2. Converting Matte:

• Oxidative treatment of the intermediate product;

Table 2

Volumes of metallurgical waste slags
Объемы отвальных металургических шлаков

Type of waste	Volume (million tons)	Main sources
Metallurgical slags	450	BCP, Kazakhmys

Table 3

Dynamics of slag accumulation (1970—2023)
Динамика накопления шлаков (1970–2023 гг.)

Years	Annual volume (thousand tons)	Accumulated volume (million tons)	Data source
1970	300	5,0	The BCP Archive (1971)
1990	450	15,2	State Report on the State of the Environment of the Republic of Kazakhstan (1991)
2000	480	20,1	Kazhydromet Report (2001)
2010	500	25,0	Kazakhmys LLP Report (2011)
2020	400	30,5	KazNII Ekologi (2021)
2023	380	~32,0	Monitoring of the MEG of the Republic of Kazakhstan (2024)

• Separation into rough copper and secondary slag;

• Process temperature: about 1250 °C.

3. The final stage:

• Slow cooling of slag;

• Transportation to the slag dumps;

• Warehousing with the formation of artificial man — made arrays.

The characteristics of the formed slags vary significantly depending on several key parameters:

1. Quality indicators of the raw materials:

• The content of the useful component (copper) is from 0.8% to 2.5%;

• The concentration of sulfur (from 15% to 25%);

• Iron impurities (up to 30%);

• The presence of related elements (lead, zinc).

2. Technological aspects of production:

• Metal extraction efficiency (85—92%);

• Copper losses with slags (0.2—1.5% of total volume);

• Features of the fluxing additive;

• Heat treatment modes.

According to the research of the KazNII of Non-Ferrous Metallurgy of the Republic of Kazakhstan (2022), the annual volume of slag formation at the BCP is about 380—450 thousand tons, while the accumulated mass of landfill slag exceeded 32 million tons. Based on the BCP environmental passport dated 2023, which states that the content of heavy metals in slags is a particular environmental problem: copper (0.2—1.5%), lead (0.1—0.5%) and zinc (0.5—2.0%), which creates a constant source of environmental pollution.

The current situation requires an integrated approach to solving environmental problems, including both the modernization of production processes and the introduction of efficient industrial waste recycling and disposal systems. The volumes of slag formation and accumulation for 1970—2023 are shown in Table 3.

Based on Table 3 and the state report of the Ministry of Agriculture of the Republic of Kazakhstan, for 2023 there is a lack of a systematic approach to waste management in mining. The accumulation of landfill slag (32 million tons) and their annual increase (380—450 thousand tons) demonstrate the absence of closed cycles of use of the generated waste, This is a characteristic problem of many mining and metallurgical enterprises, where landfills are considered as the end point of the waste life cycle, and not as a source of secondary raw materials.

Current parameters of Balkhash Copper Planter slag dumps

Based on data from remote sensing of the Earth (by the national company "Kazakhstan Garysh Sapary" in 2023) and materials from the comprehensive inventory of BMZ waste (Maps of Kazakhmys LLP slag dumps) in 2022 – 2023, the current state of BMZ slag storage facilities is characterized by the following indicators:

1. Spatial parameters:

• Total area of occupied territories: 120±5 ha;

• Maximum height of dumps: 25.3 m (northern sector);

• Average height: 18.7 m;

• Volume of accumulated slags: 32.4 million tons (as of 2023).

2. Accumulation dynamics:

• Annual volume increase: 380 – 450 thousand tons;

• Area increase rate: 1.5 – 2 ha/year;

• Storage density: 2.1 – 2.3 t/m^3.

3. The forecast indicators up to 2030 are shown in Table 4:

Based on the data in Table 4, the BCP production control reports for 2023 and the Sentinel-2 satellite survey data for 2022, the slag heaps occupy 120 hectares of land, and their area increases annually by 1.5 – 2 hectares. This leads to the withdrawal of significant territories from economic turnover and disruption of natural landscapes, which is a direct mining problem related to land reclamation and restoration, according to SanPiN RK 2.02.01-01.

The chemical and mineral composition of the slags in the landfill is shown in Table 5.

Based on the results of Table 5 and the report of the KazNII of Non-Ferrous Metallurgy, for 2022. There is a tendency that during the extraction, enrichment and processing of copper ores, a significant part of the useful components (including copper, zinc, lead) is lost with landfill slags. For example, BCP slags contain from 0.2 to 1.5% copper, which, with an accumulated volume of 32 million tons, represents significant losses of the target

Table 4

Projected indicators of slag accumulation up to 2030
Прогнозные показатели накопления шлака до 2030 года

Parameter	2023 (fact)	2030 (forecast)	Projected growth (%)
Volume, million tons	32,4	35,0 – 35,8	+8,2
Area, ha	120	130 – 135	+12,5
Height, m	25,3	27,0 – 28,5	+12,6

Table 5

The main components (%) of the chemical and mineral composition of the slags in the landfill
Основные компоненты (%) химико-минерального состава шлаков, находящихся в отвале

Component	Average Content	Range	Source
SiO_2	35,2	30 – 40	XRD analysis (KazNU, 2020)
Fe_2O_3	40,1	35 – 45	ICP-MS (KazNII, 2019)
CaO	7,5	5 – 10	GOST 5382-2019
Al_2O_3	6,8	5 – 8	BCP Report (2022)
Cu	0,8	0,2 – 1,5	EPA Method 6010D
Pb	0,3	0,1 – 0,5	SanPiN RK 1.02.002-94
Zn	0,5	0,5 – 2,0	WHO (2017)

Table 6

Concentrations of heavy metals in the air near the landfill (monitoring data for 2023)
Концентрации тяжелых металлов в воздухе близ отвалохранилища (данные мониторинга за 2023 г.)

Pollutant	Average concentration (mg/m^3)	MPC (mg/m^3)	Exceeding the MPC (times)	Source
Copper (Cu)	0.015	0.002 (daily average)	7.5	SanPiN RK No. 1.02.002-94 "Maximum permissible concentration of pollutants in atmospheric air".
Lead (Pb)	0.003	0.0003 (daily average)	10	SanPiN RK No. 1.02.002-94 "Maximum permissible concentration of pollutants in atmospheric air".
Zinc (Zn)	0.05	0.05 (one-time)	—	WHO Air Quality Guidelines (2021).

metal. This, in turn, indicates the low efficiency of mineral extraction at the stage of extraction, processing and smelting.

The mineralogical composition (X-ray phase analysis) of the dump slag of the Balkhash Metallurgical plant is represented by the following compounds:

- Fayalit (Fe_2SiO_4) — 40–50%;
- Hematite (Fe_2O_3) — 20–25%;
- Quartz (SiO_2) — 15–20%;
- Sulfides ($CuFeS_2$, PbS, ZnS) — 3–5%.

Based on the chemical and mineralogical composition of the dump slag, it can be classified as hazard class IV (as low-hazard), but due to the mobile forms of heavy metals (Cu, Pb, Zn), it requires continuous monitoring and monitoring.

Accumulated dumps can have a negative impact on the environment, in particular, wind erosion of slag heaps leads to the formation of fine dust (PM_{10} and $PM_{2.5}$) containing heavy metals. According to monitoring data based on the KazNII of Ecology "Study of atmospheric transport of heavy metals in the area of the Balkhash industrial hub" for 2022, the content of heavy metals in the air of Balkhash is shown in Table 6.

Based on the data in Table 6 and the research of the KazNII of Ecology "Study of atmospheric transport of heavy metals in the Balkhash industrial hub area" for 2022 — 2023. The formed open slag dumps are subject to wind erosion, which leads to the transfer of fine particles with heavy metals to a distance of up to 10 km. This exacerbates the problem of dust suppression in mining and especially in regions with an arid climate. The presence of such a concentration of heavy metals in the air, which can exceed the maximum permissible concentration by 10 times and move in air currents over distances up to 10 km, definitely harms the environment and public health in accordance with SanPiN RK No. 1.02.002-94 updated in 2021.

Soil contamination

Environmental monitoring shows that the area within a radius of up to 5 km from the BCP slag heaps is characterized by a critical level of soil contamination with heavy metals. The results of the samples are shown in Table 7.

Maximum permissible concentrations for heavy metals in the soil according to GOST 17.4.1.02-83 (mg/kg):

- Copper (Cu) — 3;
- Lead (Pb) — 6;
- Zinc (Zn) — 23.

Table 7 shows that the content of heavy metals, in particular copper, in the soil exceeds the MPC from 16.67 to 150 times,

Table 7

The content of heavy metals in the soil (mg/kg) and comparison with the maximum permissible values (MPC)
Содержание тяжелых металлов в почве (мг/кг) и сравнение с предельно-допустимыми показателями (ПДК)

Distance from the dump	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Exceeding the MPC Cu	Exceeding the MPC Pb	Exceeding the MPC Zn
0–500 m	450	120	350	150×	20×	15.2×
1–2 km	150	45	120	50×	7.5×	5.2×
5 km	50	15	50	16.7×	2.5×	2.2×

lead from 2.5 to 20 times, zinc from 2.2 to 15.2 times. Such soil contamination in a 5-kilometer zone can lead to ecotoxicological effects. In particular, copper (Cu): In accordance with GOST 17.4.1.02-2017, when exceeding the threshold of 60 mg/kg, it exhibits phytotoxicity, inhibiting plant growth; lead (Pb): According to the research conducted by KazNAU scientists in the scientific report "Accumulation of heavy metals in agricultural plants in Central Kazakhstan" for 2020 bioaccumulation in grain crops — in particular, the content in wheat can reach 0.5 mg/kg at a sanitary norm of 0.1 mg/kg; zinc (Zn): In high concentrations suppresses the activity of soil microflora and disrupts the balance of the microbiome [30].

Pollution of water bodies

The migration routes of pollutants are due to the following main route of heavy metals distribution — filtration of atmospheric precipitation through unprotected dumps into groundwater, then into the drainage basin of Lake Balkhash. The presence of heavy metals and their concentration in water bodies near landfills and in the coastal zone of Lake Balkhash is shown in Table 8.

Table 8 shows that the excess of copper in groundwater reaches 1200 times relative to the maximum permissible concentration, lead up to 30 times, zinc up to 210 times. The presence of heavy metals in the groundwater and the coastal zone of Lake Balkhash negatively affects the biological consequences, such as the presence of copper according to the methodology for assessing the toxicity of aquatic samples based on fish survival. (RD 52.24.643-2002.) leads to high toxicity to aquatic organisms: LC_{50} for marinka (Schizothorax intermedius) is 0.1 mg/l, according to the biomonitoring report on aquatic ecosystems of Lake Balkhash and adjacent territories of the Scientific Research Institute of Fisheries of the Republic of Kazakhstan for 2021 the presence of lead contributes to active accumulation in aquatic vegetation — the bioconcentration coefficient can reach 500.

Filtration of atmospheric precipitation through slag dumps leads to contamination of groundwater and Lake Balkhash with heavy metals (exceeding the maxi-

Table 8

Concentrations of heavy metals in water bodies (mg/l)
8-Концентрации тяжелых металлов в водных объектах (мг/л)

Water feature	Cu	Pb	Zn	MPC, mg/l
Groundwater (near landfills)	1.2	0.03	2.1	Cu: 0.001 Pb: 0.01 Zn: 0.01
Lake Balkhash (coastal area)	0.05	0.005	0.3	

mum permissible concentration for copper by up to 1200 times (Table 8)). This is a direct consequence of the possible insufficient insulation of landfills or its absence, which relates to the problems of mining ecology and requires the use of modern engineering barriers in accordance with GOST 25592-91 and RD 52.24.643-2002.

A comprehensive analysis of the current state of the Balkhash Copper Smelter's slag heaps allows us to state that the current environmental situation requires the urgent introduction of a systematic approach to industrial waste management. The key areas for solving this problem should be:

1. Development of the slag processing system:

• Creation of a specialized processing complex with a capacity of preferably at least 500 thousand tons/year;

• Implementation of combined technologies (flotation + magnetic separation) to extract valuable components.

2. Scientific support of recycling processes, including through detailed physico-chemical studies:

• X-ray diffraction analysis of the phase composition;

• Determination of thermodynamic characteristics of slag systems;

• Study of the kinetics of leaching of valuable components;

• Assessment of the reactivity of slags in various media.

Of particular importance is the need to conduct fundamental research on the physico-chemical properties of accumulated landfill slags, including:

• Determination of optimal parameters of their processing (temperature, acidity, granulometry);

• Development of mathematical models of the behavior of slag systems;

• Exploring the possibilities of integrated recycling with the production of construction and other materials;

• Assessment of the economic feasibility of various technological solutions.

The implementation of these measures requires:

• Creation of an interdisciplinary research group (metallurgists, chemists, environmentalists, etc.)

• Development of a state R&D financing program;

• Organization of an experimental testing ground for technology testing;

• Development of international cooperation in the field of industrial waste recycling.

Only an integrated approach combining modern production technologies, in-depth scientific research and effective waste management methods will solve the environmental problems associated with BCP slag heaps and create an economically attractive recycling model.

Conclusions

Based on the results of the conducted research, the following conclusions and conclusions can be drawn, in particular:

• The Balkhash Copper Plant (Kazakhmys LLP) accumulated more than 32 million tons of waste slag from 1970 to 2023, with an annual increase of 380—450 thousand tons. The projected volume by 2030 will be approximately 35—35.8 million tons, which requires urgent measures for their disposal and processing;

• The slags in the dumps contain the following heavy metals: copper, lead, zinc. Mobile forms of metals migrate into the environment, creating long-term risks;

• The slag dumps of the Balkhash copper Plant (Kazakhmys LLP), as a result of weather and climatic conditions, pollute all components of the ecosystem: the atmosphere (the average concentration of Cu reaches 0.015 mg/m^3, Pb — 0.003 mg/m^3, Zn — 0.05 mg/m^3), the soil (within a radius of 5 km from the landfills, the concentration of Cu reaches 450 mg/kg, Pb —

120 mg/kg) and water bodies (filtration into Lake Balkhash increases Cu2* levels to 1.2 mg/l) threatening biodiversity;

• There is a growing need for technological modernization, in particular, the development of a state program for slag processing with tax benefits for enterprises, as well as international cooperation for the introduction of integrated slag processing technologies.

• The problem of BCP waste slags requires a comprehensive solution at the intersection of technology, environmental protection and social policy. Inaction will lead to irreversible consequences for the ecosystem of the region.

• Comprehensive processing of slag dumps will contribute to solving a number of mining and geological problems in mining — metallurgical sector of Kazakhstan, such as the life cycle of landfills, waste, the use of landfills as secondary raw materials, the withdrawal of significant territories from economic circulation and disruption of natural landscapes, land reclamation and restoration, increased efficiency of extraction of minerals at the stage of enrichment and smelting, wind erosion, dust formation and dust suppression, gradual reduction and further absence of insulation costs landfills, and the use of modern engineering barriers.

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СПИСОК ЛИТЕРАТУРЫ

1. *Тулепова Б. М., Сапарбеков К. Б.* Экологические проблемы промышленных регионов Казахстана // Вестник КазНУ. Серия Экологическая. — 2020. — Т. 65. — № 2. — С. 45—53. DOI: 10.26577/EJE.2020.v65.i2.05.

2. *Donaev A., Kolesnikov A., Shapalov Sh., Sarapargalieva B., Ivahnuk G.* Studies of waste from the mining and metallurgical industry, with the determination of its impact on the life of the population // News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. 2022, vol. 4, pp. 55—68.

3. *Sapargaliyeva B. O., Bychkov A. Yu., Alferyeva Ya. O., Syrlybekkyzy S., Altybaeva Zh. K., Nurshakhanova L. K., Seidaliyeva L. K., Suleimenova B. S., Zhidebayeva A. E.* Thermodynamic modeling of the formation of the main minerals of cement clinker and zinc fumes in the processing of toxic technogenic waste of the metallurgical industry // Rasayan Journal of Chemistry. 2022, vol. 15, no. 3, pp. 2181—2187.

4. *Абдрахманов К. Ж.* Отходы горно-металлургического комплекса Казахстана: проблемы и решения. — Алматы: Ғылым, 2019. — 234 с.

5. *Volokitina I. E., Volokitin A. V., Kolesnikova O. G.* Effect of deformation by high-pressure torsion in a combined matrix on the properties of brass // Metallurgist. 2023, vol. 66, no. 11—12, pp. 1601—1606.

6. *Филин А. Э., Курносов И. Ю., Колесникова Л. А., Овчинникова Т. И., Колесников А. С.* К вопросу моделирования процесса осаждения пыли для условий угольной шахты // Уголь. — 2022. — № 9. — С. 67—72. DOI: 10.18796/0041-5790-2022-9-67-72.

7. *Serikbaev B. E., Zolkin A. L., Kenzhibaeva G. S., Isaev G. I., Botabaev N. E., Shapalov Sh. K., Iztleuov G. M., Suigenbayeva A. Zh., Kutzhanova A. N., Asylbekova D. D., Ashirbaev Kh. A., Alchinbaeva O. Z., Kolesnikova V. A.* Processing of non-ferrous metallurgy waste slag for its complex recovery as a secondary mineral raw material // Refractories and Industrial Ceramics. 2021, vol. 62, no. 4, pp. 375—380.

8. *Yessengaliev D., Mukhametkhan M., Mukhametkhan Y., Zhabalova G., Kelamanov B., Kolesnikova O., Shyngysbayev B., Aikozova L., Kaskataeva K., Kuatbay Y.* Studies of the possibility of improving the quality of iron ores and processing of technogenic composite iron-containing waste of metallurgical production // Journal of Composites Science. 2023, vol. 7, no. 12, article 501. DOI: 10.3390/jcs7120501.

9. *Куликова Е. Ю.*, *Баловцев С. В.*, *Скопинцева О. В.* Комплексная оценка геотехнических рисков в шахтном и подземном строительстве // Устойчивое развитие горных территорий. — 2023. — Т. 15. — № 1. — С. 7—16. DOI: 10.21177/1998-4502-2023-15-1-7-16.

10. *Садыкова Г. К.* Утилизация золошлаковых отходов ТЭС Казахстана. — Караганда: Изд-во КарГТУ, 2022. — 187 с.

11. *Muratov B., Shapalov S., Syrlybekkyzy S., Volokitina I., Zhunisbekova D., Takibayeva G., Nurbaeva F., Aubakirova T., Nurshakhanova L., Koishina A.* Physico-chemical study of the possibility of utilization of coal ash by processing as secondary raw materials to obtain a composite cement clinker // Journal of Composites Science. 2023, vol. 7, no. 6, article 234. DOI: 10.3390/jcs7060234.

12. *Bedov A. I.*, *Gabitov A. I.*, *Domarova E. V.*, *Kolesnikov A. S.* Investigation of the stress-strain state of domical masonry vaults // Construction Materials and Products. — 2023, vol. 6, no. 6, article 6.

13. *Ивахнюк Г. К.*, *Аверьянова Н. А.*, *Талдыкин Ю. А.* Переработка отходов химической промышленности // Химия и технология. — 2020. — Т. 15. — № 3. — С. 112—125. DOI: 10.15372/khim20200312.

14. *Abzhalov R., Sataev M., Koshkarbayeva S., Sagitova G., Smailov B., Azimov A., Serikbaeva B., Fediuk R., Amran M.* Studies of the application of electrically conductive composite copper films to cotton fabrics // Journal of Composites Science. 2022, vol. 6, no. 11, article 349. DOI: 10.3390/jcs6110349.

15. *Filin A., Kolbina I., Seidaliyev A., Koibakova S., Mankesheva O.* Comparison of the quality of gas equipment at metallurgical and coke-chemical enterprises and production plants // Polish Journal of Environmental Studies. 2024, vol. 33, no. 3, pp. 2999—3008. DOI: 10.15244/pjoes/177442.

16. *Мустафин А. С.* Использование промышленных отходов в строительных материалах. — Нур-Султан: КазАТУ, 2021. — 156 с.

17. *Zhangabay N., Suleimenov U., Utelbayeva A., Buganova S.* Experimental research of the stress-strain state of prestressed cylindrical shells taking into account temperature effects // Case Studies in Construction Materials. 2022, vol. 18, no. 2, article e01776. DOI: 10.1016/j.cscm.2022.e01776.

18. *Klyuev S. V.*, *Slobodchikova N. A.*, *Saidumov M. S.*, *Abumuslimov A. S.*, *Mezhidov D. A.*, *Khezhev T. A.* Application of ash and slag waste from coal combustion in the construction of the earth bed of roads // Construction Materials and Products. 2024, vol. 7, no. 6, article 3.

19. *Mamyrbekova A., Kassymova M. K., Mamyrbekova A.* Effect of pH on the electroreduction of Cadmium(II) and Lead(II) ions on electrodes in the presence of surfactants // Russian Journal of Physical Chemistry A. 2019, vol. 93, no. 3, pp. 442—446. DOI: 10.1134/S0036024419030129.

20. *Дюсембаева Н. К.* Гигиенические и экологические аспекты г. Балхаша // Гигиена труда и медицинская экология. — 2015. — № 4 (49).

21. *Куанышбаев Т.*, *Уйсимбаева Г. У.*, *Жакенова С. Р.* Гигиенические аспекты окружающей среды и здоровья населения города Балхаш // Медицина и экология. — 2009. — № 3 (52).

22. *Сапарбаев М. К.*, *Искаков Н. Т.* Структурные особенности промышленного развития Казахстана // Экономика и статистика. — 2021. — № 4 (112). — С. 78—85. DOI: 10.26577/ES.2021.v112.i4.08.

23. *Абдикаримова К.* Современное состояние Казахстана и развитие промышленной политики регионов // Вестник евразийской науки. — 2017. — № 5 (42).

24. *Ермакова Ж. А.* Промышленная политика как ключевой фактор перевода экономики региона на высший технологический уклад // Экономика региона. — 2005. — № 3. — С. 128—132.

25. *Wagner T. P.* Historical industrial waste: Global lessons for remediation // Journal of Environmental Management. 2023, vol. 325, article 116415. DOI: 10.1016/j.jenvman.2022.116415.

26. *Naizabekov A. B.*, *Latypova M. A.*, *Fedorova T. D.*, *Mamitova A. D.* Current trends to obtain metals and alloys with ultrafine-grained structure // Progress in Physics of Metals. 2022, vol. 23, no. 4, pp. 629—657.

27. *Конкабаева А. Е.*, *Ишмуратова М. Ю.* Оценка накопления тяжелых металлов в почве, воде и растениях промышленных регионов Карагандинской области. — Караганда: ТОО «Полиграфист», 2016. — 112 с.

28. *Kassymova M. K.*, *Nauryzbaev M. K.*, *Mamyrbekova Aigul, Zhylysbayeva G. N., Mamyrbekova Aizhan* Effect of surfactants on the reduction of Cadmium(II) ions on Cadmium electrode // Russian Journal of Physical Chemistry A. 2019, vol. 93, no. 5, pp. 980—985. DOI: 10.1134/S0036024419050170.

29. *Kocherov Y., Kolesnikov A., Makulbekova G., Mamitova A., Ramatullaeva L., Medeshev B., Kolesnikova O.* Investigation of the physico-chemical and mechanical properties of expanded ceramsite granules made on the basis of coal mining waste // Journal of Composites Science. — 2024, vol. 8, no. 8, article 306. DOI: 10.3390/jcs8080306.

30. *Chandrangsu P., Rensing C., Helmann J. D.* Metal homeostasis and resistance in bacteria // Nature Reviews Microbiology. 2017, vol. 15, pp. 338—350. DOI: 10.1038/nrmicro.2017.15. ГИАБ

REFERENCES

1. Tulepova B. M., Saparbekov K. B. Ecological problems of industrial regions of Kazakhstan. *Eurasian Journal of Ecology*. 2020, vol. 65, no. 2, pp. 45—53. [In Russ]. DOI: 10.26577/EJE.2020.v65.i2.05.

2. Donaev A., Kolesnikov A., Shapalov Sh., Sarapargalieva B., Ivahnuk G. Studies of waste from the mining and metallurgical industry, with the determination of its impact on the life of the population. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*. 2022, vol. 4, pp. 55—68.

3. Sapargaliyeva B. O., Bychkov A. Yu., Alferyeva Ya. O., Syrlybekkyzy S., Altybaeva Zh. K., Nurshakhanova L. K., Seidaliyeva L. K., Suleimenova B. S., Zhidebayeva A. E. Thermodynamic modeling of the formation of the main minerals of cement clinker and zinc fumes in the processing of toxic technogenic waste of the metallurgical industry. *Rasayan Journal of Chemistry*. 2022, vol. 15, no. 3, pp. 2181—2187.

4. Abdrakhmanov K. Zh. *Otkhody gorno-metallurgicheskogo kompleksa Kazakhstana: problemy i resheniya* [Waste of the mining and metallurgical complex of Kazakhstan: problems and solutions], Almaty, 2019, 234 p.

5. Volokitina I. E., Volokitin A. V., Kolesnikova O. G. Effect of deformation by high-pressure torsion in a combined matrix on the properties of brass. *Metallurgist*. 2023, vol. 66, no. 11—12, pp. 1601—1606.

6. Filin A. E., Kurnosov I. Yu., Kolesnikova L. A., Ovchinnikova T. I., Kolesnikov A. S. Description of the methodology for conducting an experiment on dust deposition of mining and metallurgical production. *Ugol'*. 2022, no. 9, pp. 67—72. [In Russ]. DOI: 10.18796/0041-5790-2022-9-67-72.

7. Serikbaev B. E., Zolkin A. L., Kenzhibaeva G. S., Isaev G. I., Botabaev N. E., Shapalov Sh. K., Iztleuov G. M., Suigenbayeva A. Zh., Kutzhanova A. N., Asylbekova D. D., Ashirbaev Kh. A., Alchinbaeva O. Z., Kolesnikova V. A. Processing of non-ferrous metallurgy waste slag for its complex recovery as a secondary mineral raw material. *Refractories and Industrial Ceramics*. 2021, vol. 62, no. 4, pp. 375—380.

8. Yessengaliev D., Mukhametkhan M., Mukhametkhan Y., Zhabalova G., Kelamanov B., Kolesnikova O., Shyngysbayev B., Aikozova L., Kaskataeva K., Kuatbay Y. Studies of the possibility of improving the quality of iron ores and processing of technogenic composite iron-containing waste of metallurgical production. *Journal of Composites Science*. 2023, vol. 7, no. 12, article 501. DOI: 10.3390/jcs7120501.

9. Kulikova E. Yu., Balovtsev S. V., Skopintseva O. V. Complex estimation of geotechnical risks in mine and underground construction. *Sustainable Development of Mountain Territories*. 2023, vol. 15, no. 1, pp. 7—16. [In Russ]. DOI: 10.21177/1998-4502-2023-15-1-7-16.

10. Sadykova G. K. *Utilizatsiya zoloshlakovykh otkhodov TES Kazakhstana* [Utilization of ash and slag waste from thermal power plants in Kazakhstan], Karaganda, Izd-vo KarGTU, 2022, 187 p.

11. Muratov B., Shapalov S., Syrlybekkyzy S., Volokitina I., Zhunisbekova D., Takibayeva G., Nurbaeva F., Aubakirova T., Nurshakhanova L., Koishina A. Physico-chemical study of the possibility of utilization of coal ash by processing as secondary raw materials to obtain a composite cement clinker. *Journal of Composites Science*. 2023, vol. 7, no. 6, article 234. DOI: 10.3390/jcs7060234.

12. Bedov A. I., Gabitov A. I., Domarova E. V., Kolesnikov A. S. Investigation of the stress-strain state of domical masonry vaults. *Construction Materials and Products*. 2023, vol. 6, no. 6, article 6.

13. Ivakhnyuk G. K., Averyanova N. A., Taldykin Yu. A. Processing of chemical industry waste. *Chemistry and Technology*. 2020, vol. 15, no. 3, pp. 112—125. [In Russ]. DOI: 10.15372/khim20200312.

14. Abzhalov R., Sataev M., Koshkarbayeva S., Sagitova G., Smailov B., Azimov A., Serikbaeva B., Fediuk R., Amran M. Studies of the application of electrically conductive composite copper films to cotton fabrics. *Journal of Composites Science*. 2022, vol. 6, no. 11, article 349. DOI: 10.3390/jcs6110349.

15. Filin A., Kolbina I., Seidaliyev A., Koibakova S., Mankesheva O. Comparison of the quality of gas equipment at metallurgical and coke-chemical enterprises and production plants. *Polish Journal of Environmental Studies*. 2024, vol. 33, no. 3, pp. 2999 – 3008. DOI: 10.15244/pjoes/177442.

16. Mustafin A. S. *Ispol'zovanie promyshlennykh otkhodov v stroitel'nykh materialakh* [Use of industrial waste in building materials], Nur-Sultan, KazATU, 2021, 156 p.

17. Zhangabay N., Suleimenov U., Utelbayeva A., Buganova S. Experimental research of the stress-strain state of prestressed cylindrical shells taking into account temperature effects. *Case Studies in Construction Materials*. 2022, vol. 18, no. 2, article e01776. DOI: 10.1016/j.cscm.2022.e01776.

18. Klyuev S. V., Slobodchikova N. A., Saidumov M. S., Abumuslimov A. S., Mezhidov D. A., Khezhev T. A. Application of ash and slag waste from coal combustion in the construction of the earth bed of roads. *Construction Materials and Products*. 2024, vol. 7, no. 6, article 3.

19. Mamyrbekova A., Kassymova M. K., Mamyrbekova A. Effect of pH on the electroreduction of Cadmium(II) and Lead(II) ions on electrodes in the presence of surfactants. *Russian Journal of Physical Chemistry A*. 2019, vol. 93, no. 3, pp. 442 – 446. DOI: 10.1134/S0036024419030129.

20. Dyusembayeva N. K. Hygienic and ecological aspects of Balkhash city. *Gigiena truda i meditsinskaya ekologiya*. 2015, no. 4 (49). [In Russ].

21. Kuanyshbaev T., Uyisimbayeva G. U., Zhakenova S. R. Hygienic aspects of the environment and public health in Balkhash city. *Meditsina i ekologiya*. 2009, no. 3 (52). [In Russ].

22. Saparbaev M. K., Iskakov N. T. Structural features of industrial development of Kazakhstan. *Ekonomika i statistika*. 2021, no. 4 (112), pp. 78 – 85. [In Russ]. DOI: 10.26577/ES.2021.v112.i4.08.

23. Abdikarimova K. Current state of Kazakhstan and development of industrial policy in the regions. *The Eurasian Scientific Journal*. 2017, no. 5 (42). [In Russ].

24. Ermakova Zh. A. Industrial policy as a key factor in the transition of the regional economy to a higher technological structure. *Ekonomika regiona*. 2005, no. 3, pp. 128 – 132. [In Russ].

25. Wagner T. P. Historical industrial waste: Global lessons for remediation. *Journal of Environmental Management*. 2023, vol. 325, article 116415. DOI: 10.1016/j.jenvman.2022.116415.

26. Naizabekov A. B., Latypova M. A., Fedorova T. D., Mamitova A. D. Current trends to obtain metals and alloys with ultrafine-grained structure. *Progress in Physics of Metals*. 2022, vol. 23, no. 4, pp. 629 – 657.

27. Konkabaeva A. E., Ishmuratova M. Yu. *Otsenka nakopleniya tyazhelykh metallov v pochve, vode i rasteniyakh promyshlennykh regionov Karagandinskoy oblasti* [Assessment of heavy metal accumulation in soil, water, and plants in industrial regions of Karaganda Oblast], Karaganda, 2016, 112 p.

28. Kassymova M. K., Nauryzbaev M. K., Mamyrbekova Aigul, Zhylysbayeva G. N., Mamyrbekova Aizhan Effect of surfactants on the reduction of Cadmium(II) ions on Cadmium electrode.*Russian Journal of Physical Chemistry A*. 2019, vol. 93, no. 5, pp. 980 – 985. DOI: 10.1134/S0036024419050170.

29. Kocherov Y., Kolesnikov A., Makulbekova G., Mamitova A., Ramatullaeva L., Medeshev B., Kolesnikova O. Investigation of the physico-chemical and mechanical properties of expanded ceramsite granules made on the basis of coal mining waste. *Journal of Composites Science*. 2024, vol. 8, no. 8, article 306. DOI: 10.3390/jcs8080306.

30. Chandrangsu P., Rensing C., Helmann J. D. Metal homeostasis and resistance in bacteria. *Nature Reviews Microbiology*. 2017, vol. 15, pp. 338 – 350. DOI: 10.1038/nrmicro.2017.15.

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