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CURRENT STATE AND DEVELOPMENT TRENDS OF INTEGRATED UTILIZATION OF TECHNOGENIC WASTES IN THE MINING AND METALLURGICAL INDUSTRY

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Abstract. This study examines the integrated utilization of technogenic wastes generated in mining and metallurgical production, focusing on the recovery of valuable metals from secondary ores accumulated at the Navoi Mining and Metallurgical Combine. Laboratory-scale experiments were conducted to evaluate the beneficiation potential of tailings materials using selective leaching methods. The results show that copper is mainly concentrated in the coarse fraction, while gold and sulfur exhibit variable recovery efficiencies depending on sample composition and particle size. The obtained hydrometallurgical concentrates contained 35–70% copper, 400–800 g/t gold, and 400–1600 g/t silver, with average recovery rates of 52.5%, 48.7%, and 25.0%, respectively. Although the achieved results confirm the potential for secondary resource utilization, the recovery efficiency remains suboptimal, highlighting the need for further technological improvements and optimization of leaching parameters to enhance metal recovery from technogenic raw materials.

Keywords: technogenic waste; secondary ores; beneficiation; selective leaching; metal recovery; mining industry

Annotatsiya. Ushbu tadqiqotda Navoiy kon-metallurgiya kombinatida to‘plangan ikkilamchi rudalardan qimmatbaho metallarni ajratib olishga alohida e’tibor qaratgan holda, konchilik va metallurgiya ishlab chiqarishida hosil bo‘ladigan texnogen chiqindilardan kompleks foydalanish ko‘rib chiqiladi. Tanlangan yuvish usullaridan foydalangan holda chiqindilarni qayta ishlash potentsialini baholash uchun laboratoriya miqyosidagi tajribalar o'tkazildi. Natijalar shuni ko'rsatadiki, mis asosan qo'pol fraksiyada to'plangan, oltin va oltingugurt esa namuna tarkibi va zarracha hajmiga qarab o'zgaruvchan qayta tiklash samaradorligiga ega. Olingan gidrometallurgik kontsentratlarda 35-70% mis, 400-800 g/t oltin va 400-1600 g / t kumush mavjud bo'lib, o'rtacha tiklanish darajasi mos ravishda 52,5%, 48,7% va 25,0% ni tashkil qiladi.Kalit so'zlar: texnogen chiqindilar; ikkilamchi rudalar; boyitish; selektiv eritma; metallni qayta tiklash; tog'-kon sanoatia qolmoqda, bu esa texnogen xom ashyodan metallni qayta tiklashni yaxshilash uchun texnologik takomillashtirish va yuvish parametrlarini optimallashtirish zarurligini ta'kidlaydi.

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Kalit so'zlar: texnogen chiqindilar; ikkilamchi rudalar; boyitish; selektiv eritma; metallni qayta tiklash; tog'-kon sanoati

Аннотация. В данном исследовании рассматривается комплексная утилизация техногенных отходов, образующихся в горнодобывающем и металлургическом производстве, с акцентом на извлечение ценных металлов из вторичных руд, накопленных на Навоийском горно-металлургическом комбинате. Были проведены лабораторные эксперименты для оценки потенциала обогащения хвостов с использованием методов селективного выщелачивания. Результаты показывают, что медь в основном концентрируется в крупной фракции, в то время как золото и сера демонстрируют различную эффективность извлечения в зависимости от состава пробы и размера частиц. Полученные гидрометаллургические концентраты содержали 35-70% меди, 400-800 г/т золота и 400-1600 г/т серебра при среднем извлечении 52,5%, 48,7% и 25,0% соответственно. Хотя достигнутые результаты подтверждают потенциал использования вторичных ресурсов, эффективность извлечения остается неоптимальной, что указывает на необходимость дальнейших технологических усовершенствований и оптимизации параметров выщелачивания для повышения извлечения металла из техногенного сырья.

Ключевые слова: техногенные отходы; вторичные руды; обогащение; селективное выщелачивание; извлечение металлов; горнодобывающая промышленность

INTRODUCTION.

At present, one of the most pressing challenges facing mining and metallurgical enterprises is the efficient processing of technogenic waste accumulated over many years and the maximum recovery of valuable components contained therein. This issue is closely linked to increasing production efficiency, expanding the mineral raw material base, and reducing the technogenic burden on the environment.

In this context, effective technological solutions aimed at the direct metallurgical processing of technogenic waste are being introduced at the Almalyk Mining and Metallurgical Combine. In particular, the commissioning of a slag crushing unit for converter slags generated in the Metallurgical Workshop of the Copper Smelting Plant has made it possible to significantly increase the recovery rates of copper, gold, and silver from technogenic waste. Under the new technology, converter slags and zinc production residues are directly smelted in a Vanyukov furnace, increasing the copper recovery rate to 93.87 percent, which ensures substantially higher efficiency compared to previously applied

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beneficiation schemes. As a result of the implemented technological solutions, annual savings exceeding 7 billion Uzbek soums have been achieved, along with the additional production of non-ferrous and precious metal products.

Similar approaches to the processing of technogenic waste are also being implemented at the Navoi Mining and Metallurgical Combine. Special attention is being paid to increasing the processing capacity of technogenic waste generated as a result of long-term mining and hydrometallurgical operations. Measures are being undertaken at Hydrometallurgical Plant No. 7 to increase the annual processing volume of such waste to 25 million tonnes. The commissioning of new milling complexes contributes to the involvement of technogenic waste as secondary raw materials, the additional recovery of valuable components, and the reduction of environmental load.

The presented data demonstrate that the implementation of integrated technologies for the processing of technogenic waste in the mining and metallurgical industry is characterized by high economic and environmental efficiency and substantiates the necessity of further developing scientific research in this field.

PURPOSE AND OBJECTIVES OF THE STUDY.

The purpose of this study is to evaluate the efficiency of technologies and technical means used for placing technogenic formations and wastes generated in mining and metallurgical production into underground mined-out voids as components of backfill mixtures of various compositions and strengths, as well as for their utilization in waste storage facilities.

To achieve this purpose, the following objectives were set:

✓ To identify the main directions for the utilization of mining and metallurgical production wastes.

✓ To develop and evaluate technological schemes for the use of mining and metallurgical wastes as components of solidifying backfill mixtures in underground mined-out voids and to assess the degree of their utilization.

✓ To create a cadastre of mining and metallurgical wastes and determine the possible ways of their reuse for industrial and economic needs.

The development of environmentally safe technologies is of particular importance for mining and processing enterprises belonging to the mining and metallurgical raw material base. These industries are characterized by the formation of a large amount of technogenic waste per unit of finished product, including wastes containing natural radioactive components.

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Such wastes not only represent a potential source of environmental hazard, but also constitute technogenic raw materials with possibilities for reprocessing and secondary utilization.

RESULTS AND DISCUSSION.

Most ores of heavy non-ferrous and rare metals are composed of relatively low-grade polymetallic rocks. When an ore is classified as polymetallic and contains sufficient quantities of several valuable elements, it is necessary to separate not only the barren gangue minerals but also to isolate each metal into a distinct product suitable for independent metallurgical processing. This approach is referred to as selective beneficiation.

The obtained results confirm that the composition and distribution of technogenic wastes at the Navoi Mining and Metallurgical Combine create favorable conditions for the recovery of valuable metals through selective beneficiation.

At the Navoi Mining and Metallurgical Combine, significant quantities of technogenic waste have accumulated in the first tailings storage facility of the copper beneficiation plant. In the lower zone of this facility—approximately one hundred meters deep—around 500 million tonnes of waste material with the following average content of valuable components have been deposited: copper – 0.18–0.20%, molybdenum – 0.0029–0.0033%, gold – 0.304 g/t, and silver – 1.0–1.8 g/t.

The fine grain size of the dump material represents a favorable factor that facilitates the development of a cost-effective processing technology. The first tailings storage facility of the CBP covers an area of approximately 2×4 km and is divided along its perimeter into 98 survey points and 20 cross-sections. The distance between survey points is about 100 meters, while the distance between sections is 500 meters. The tailings have been continuously deposited since 1961, and currently about 20% of the plant's ongoing waste is directed to this facility.

The distribution of secondary raw material reserves across various copper grades (Table 1) shows that copper is mainly concentrated in the coarse fraction (+0.2 mm). In the medium fraction (−0.2 +0.074 mm), its content remains at a satisfactory level, whereas in the fine fraction (−0.074 mm), the concentration of copper is relatively low, increasing only when more than 25–30% of the fine fraction is processed.

This analysis highlights the potential of reprocessing the technogenic wastes at NMMC for the recovery of valuable non-ferrous and rare metals, thereby expanding the mineral resource base and improving the overall sustainability of metallurgical production.

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To better understand the quantitative potential of secondary raw materials, calculations were made to determine the reserves and metal content within the tailings accumulated at the copper beneficiation plant. The results are summarized in Table 1.

Table 1.

Calculation of Secondary Raw Material Reserves

Copper grade in ore, %	Ore reserves, thousand t	Cu, % (thousand t)	Mo, % (thousand t)	S, % (thousand t)	Au, g/t (kg)	Ag, g/t (t)
0.20	25,078	0.22 (55.17)	0.004 (0.98)	1.3 (333)	0.3 (7,524)	1.3 (33)
0.15	83,485	0.19 (158.5)	0.003 (2.88)	1.5 (1,219)	0.3 (25,054)	1.3 (110)
0.10	164,377	0.17 (283)	0.003 (5.26)	1.5 (2,380)	0.3 (49,313)	1.3 (218)

As seen from the data presented in Table 1, the concentration of copper is predominantly associated with the coarse fraction, while finer fractions contain lower metal values. This distribution pattern directly influences the efficiency of subsequent beneficiation processes and highlights the importance of fraction-based processing strategies.

Based on the above findings, experimental work was initiated to evaluate the technological feasibility and effectiveness of processing these fractions under laboratory conditions.

To determine the feasibility and efficiency of utilizing the sand fraction of ores for the complete extraction of valuable components, three laboratory-scale experiments were conducted using samples collected from tailings storage facilities No. 1, 2, and 3. The experimental data are presented in Table 2. The optimal beneficiation sequence was established based on the obtained results.

Experimental tests were carried out using the *selective leaching method* on secondary ores derived from the tailings storage facilities. As a result, hydrometallurgical concentrates were obtained containing 35–70% copper, 400–800 g/t gold, and 400–1600 g/t silver.

On average, during the extraction of valuable components from secondary ores, the recovery rates were as follows: copper – 52.5%, gold – 48.7%, and silver – 25.0%. The obtained technical and economic indicators are considered insufficient, which highlights the need for developing new technological solutions to enhance the recovery efficiency of valuable metals.

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Table 2.

Results of the Study on the Beneficiation Ability of Secondary Ores

Sample No.	Yield, %	Recovery into Concentrate, % (Cu)	Recovery into Concentrate, % (Au)	Recovery into Concentrate, % (S)	Cu, %	Au, g/t
1	3.31	73.85	50.67	38.13	3.30	6.0
2	3.81	74.76	54.30	35.70	2.99	6.0
3	3.49	72.53	63.98	49.39	2.92	5.5

The experimental results presented in Table 2 demonstrate that, although the recovery of copper remains relatively stable, the recovery of gold and sulfur exhibits considerable variation depending on the sample characteristics. These variations are primarily related to differences in mineral composition and particle size distribution among the tested samples.

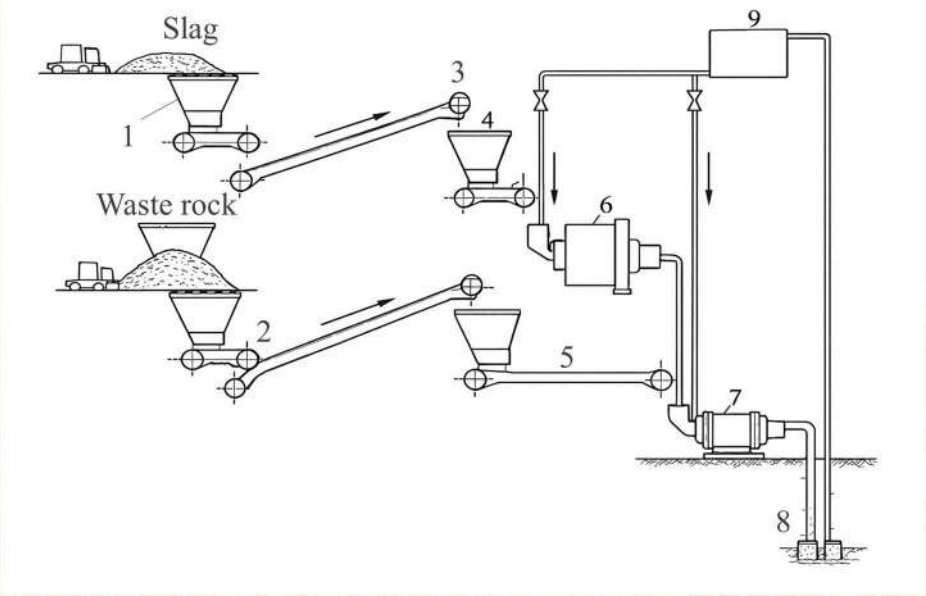


Figure 1. Technological scheme of the aggregate complex: 1 – receiving hopper; 2 – feeder; 3 – conveyor; 4 – collecting hopper; 5 – dispenser; 6 – ball mill; 7 – mixer; 8 – receiving funnel; 9 – water tank for slurry preparation.

This evaluation was carried out based on the output indicators per one tonne of commercial ore and the degree to which these wastes are utilized for backfilling mined-out voids. The assessment was performed using the following formulas:

$$k_{u,r} = P_r / \gamma_r,$$

$$k_{u,x} = P_x / \gamma_x,$$

$$k_{u,o} = (P_r + P_x + P_o) / \gamma_r.$$

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Here, $k_{u,r}$ $k_{u,x}$, and $k_{u,0}$ represent the coefficients of utilization of, respectively, rock materials, beneficiation wastes, and other wastes for backfilling mined-out voids.

P_r and P_x denote the mass (t/m^3) of rocks and wastes, respectively, within one cubic meter of the accumulated material. γ_r and γ_x are the densities (t/m^3) of rocks and wastes in the massif, respectively. P_r, P_x, and P_o represent the masses (t/m^3) of balanced ore, heap leaching waste, and hydrometallurgical processing waste, respectively, based on the content of valuable components.

The relationship between recovery efficiency and sample composition is illustrated in Figure 2, which clearly shows the variation of copper, gold, and sulfur recovery across the three samples studied.

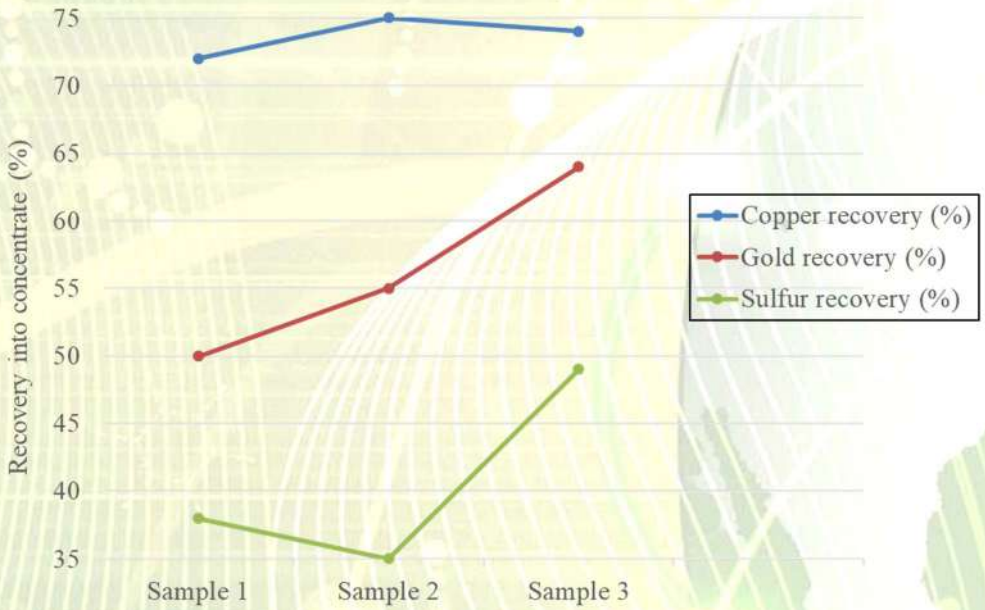


Figure 2. Recovery of Valuable Components from Secondary Ores

Overall, the obtained results confirm that the secondary ores stored in the tailings of the NMMC contain recoverable quantities of valuable components. However, the relatively low recovery rates indicate the necessity of further improving leaching conditions, reagent selection, and process optimization to enhance the overall metal recovery efficiency.

CONCLUSION.

The conducted research demonstrates that the technogenic wastes accumulated at the Navoi Mining and Metallurgical Combine represent a significant potential source of secondary raw materials for the recovery of valuable non-ferrous and precious metals. Laboratory investigations confirmed that selective leaching of tailings-derived secondary ores enables the extraction of copper, gold, and silver with moderate recovery efficiencies. However, the results

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also indicate that current recovery levels are insufficient for large-scale industrial implementation without further technological optimization.

To enhance process efficiency, it is necessary to improve the parameters of leaching, reagent composition, and beneficiation circuit design. The implementation of integrated processing technologies will not only contribute to the economic efficiency of metallurgical production but also ensure the sustainable utilization of technogenic resources while reducing their environmental impact. Thus, the development of advanced, eco-efficient methods for reprocessing technogenic waste is of strategic importance for the mining and metallurgical industry of Uzbekistan.

The conducted research confirms that technogenic wastes accumulated at the Navoi Mining and Metallurgical Combine possess substantial potential as secondary raw materials for the extraction of valuable non-ferrous and noble metals. Laboratory analyses have demonstrated that selective leaching of tailings-derived materials enables the recovery of copper, gold, and silver with moderate efficiency. Nevertheless, the obtained recovery rates remain below industrially viable levels, emphasizing the necessity for process enhancement.

Future improvements should focus on optimizing leaching parameters, refining reagent systems, and modernizing beneficiation circuit designs to achieve higher extraction yields. The adoption of integrated and eco-efficient technologies for technogenic waste reprocessing will not only improve the economic performance of metallurgical operations but also contribute to environmental sustainability by reducing industrial waste accumulation. In this regard, the continued development of innovative, resource-efficient, and environmentally responsible methods for secondary resource utilization holds strategic importance for the sustainable growth of Uzbekistan's mining and metallurgical industry.

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