Integrated Hydrometallurgical Strategies for the Valorization of Technogenic Solutions and Waste in Copper Production

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Abstract – This study investigates the efficiency of extracting valuable and rare metals from technogenic solutions and mother liquors generated at the Almalyk Mining and Metallurgical Combine (Almalyk MMC). Using methods of ionic flotation and selective carbonate-based precipitation, the research establishes optimal parameters for recovering Copper (Cu), Nickel (Ni), Molybdenum (Mo), and rare elements like Dysprosium (Dy) and Tellurium (Te). Results indicate that ionic flotation using sodium diethyldithiocarbamate (DEDTC) achieves copper recovery rates of 98.6–99.5%, while thermodynamic modelling via potential-pH (E-pH) diagrams identifies specific zones for rare metal stability. The findings provide a pathway for industrial decarbonization and secondary resource utilisation, transforming environmental liabilities into economic assets.

Keywords: Ion flotation, technogenic solutions, metal recovery, decarbonization, hydrometallurgy.

Интегрированные Гидрометаллургические Стратегии по Утилизации Техногенных Растворов и Отходов Медного Производства

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Абстракт – В данной работе исследуется эффективность извлечения ценных и редких металлов из техногенных растворов и маточных щелоков, образующихся на Алмалыкском ГМК. Используя методы ионной флотации и селективного карбонатного осаждения, исследование устанавливает оптимальные параметры для извлечения меди (Cu), никеля (Ni), молибдена (Mo) и редких элементов, таких как диспрозий (Dy) и теллур (Te). Результаты показывают, что ионная флотация с использованием диэтилдитиокарбамата натрия позволяет

достичь степени извлечения меди 98,6–99,5%, а термодинамическое моделирование через диаграммы потенциал-pH определяет зоны стабильности редких металлов.

Ключевые слова: Ионная флотация, техногенные растворы, извлечение металлов, декарбонизация, гидрометаллургия.

Mis Ishlab Chiqarishning Texnogen Eritmalari va Chiqindilarini Qayta Ishlashda Kompleks Gidrometallurgik Strategiyalar

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Annotatsiya – Ushbu tadqiqotda "Olmaliq KMK" AJda hosil bo‘ladigan texnogen eritmalar va ona eritmalardan qimmatbaho va noyob metallarni ajratib olish samaradorligi o'rganildi. Ionli flotatsiya va selektiv karbonatli cho'ktirish usullaridan foydalanib, Mis (Cu), Nikel (Ni), Molibden (Mo) hamda Disprosiy (Dy) va Tellur (Te) kabi noyob elementlarni ajratib olishning optimal parametrlari belgilandi. Natijalar shuni ko'rsatadiki, natriy diyetilditiokarbamat yordamida ionli flotatsiya misni 98,6–99,5% gacha ajratib olish imkonini beradi.

Kalit so‘zlar: Ionli flotatsiya, texnogen eritmalar, metallarni ajratib olish, dekarbonizatsiya, gidrometallurgiya.

1. Introduction. The modern metallurgical landscape is increasingly defined by the need for deep processing and the use of secondary technogenic resources [1, 2]. At the Almalyk Mining and Metallurgical Combine (Almalyk MMC), one of Uzbekistan’s industrial cornerstones, the production cycle generates significant volumes of liquid waste, including mother solutions from the vitriol plant and acidic effluents from gas-cleaning stages [3,4]. Historically, these solutions, containing high concentrations of impurities and valuable metals such as Nickel and Copper, were treated as environmental burdens or resulted in irretrievable metal losses [5-7].

The recovery of these metals is not merely an economic objective but a critical component of industrial decarbonization. By shifting from primary ore extraction to the valorisation of waste solutions, metallurgical enterprises can significantly reduce their carbon footprint and energy intensity [8]. This research aims to explore the feasibility of extracting ions of copper, nickel, and molybdenum, as well as rare elements like dysprosium and tellurium, using advanced hydrometallurgical techniques such as ionic flotation and selective precipitation [9].

2. Materials and Methods

2.1 Characterisation of Solutions

The primary objects of study were the mother solutions of the vitriol plant and technogenic solutions formed from washing technological gases at the Copper Smelter [10]. Chemical analysis revealed a complex composition:

Mother Solution: Copper (62.5 g/l), Nickel (12.5 g/l), and Sulfuric acid (7 g/l) [11].

Technogenic Gas Solutions: Significant concentrations of Tin (205.32 mg/l), Dysprosium (112.39 mg/l), and Tellurium (92.04 mg/l) [12].

2.2 Experimental Setup and Reagents

The research utilised a column-type apparatus for the ion flotation process, chosen for its high productivity and efficiency at low metal concentrations [13]. For selective recovery, the following reagents and collectors were tested:

Collectors: Sodium diethyldithiocarbamate (DEDTC), amyl xanthogenate, and ethyl xanthogenate.

pH Regulators: Sodium hydroxide (NaOH) and Sulfuric acid (H_2SO_4)

Modelling: Thermodynamic analysis and Potential-pH (E-pH) diagrams were generated using FactSage 8.2 software to predict stable phases for rare metals.

3. Results

3.1 Efficiency of Ionic Flotation

Experiments demonstrated that the degree of metal extraction is heavily dependent on the pH value and the concentration of the collector. Using DEDTC as a collector at 110% of the stoichiometric amount, copper recovery reached 98.6–99.5% within 600 seconds of flotation.

Metal Ion	Optimal pH	Collector	Extraction Degree (%)
Copper (Cu)	5.0 – 5.5	Sodium DEDTC	98.6 – 99.5
Nickel (Ni)	6.0	Sodium DEDTC	54.0 – 74.0
Molybdenum (Mo)	3.0 – 3.5	Sodium DEDTC	85.0 – 89.0
Zinc (Zn)	5.5 – 6.0	Sodium DEDTC	75.0 – 82.0

Table 1: Optimal extraction parameters and recovery rates for target metals.

3.2 Selective Precipitation of Rare Metals

Thermodynamic modelling identified that Dysprosium (Dy) can be effectively separated in alkaline media, pH > 7.5, as Dy_2O_3. Tellurium (Te) is best recovered in an oxidising neutral environment (pH = 5-8) as TeO_2, while Molybdenum (Mo) precipitates as MoO_2 in the pH range of 5–9.

4. Discussion

4.1 Comparison of Methods

While traditional methods like reagent precipitation and ion exchange are energy-intensive and often involve secondary pollutants, ionic flotation offers a low-investment alternative with high productivity [14]. The research highlights that DEDTC is superior to xanthogenates due to its ability to form strong, insoluble complexes even in acidic environments.

4.2 Industrial and Environmental Significance

The integration of these hydrometallurgical routes into the Almalyk MMC production chain supports the transition toward a circular economy. The process flowsheet for valorisation is summarised below:

The recovery of Nickel from mother solutions is particularly vital for Uzbekistan, which lacks natural nickel deposits and relies entirely on imports. Furthermore, the selective extraction of metals like Tellurium and Molybdenum reduces the toxic load on wastewater systems, aligning with global decarbonization goals by reducing the energy required for primary raw material processing.

5. Conclusion

The investigation confirms the high technical and economic potential of extracting metals from the technogenic solutions of Almalyk MMC. Key conclusions include:

Ionic flotation using sodium DEDTC is highly effective for copper and molybdenum recovery, achieving near-total extraction under optimised pH conditions.

Thermodynamic modelling via FactSage provides a reliable framework for the selective precipitation of rare elements like Dysprosium and Tellurium from complex gas-wash solutions.

Valorisation of waste acts as a pragmatic pathway for decarbonization, turning secondary resources into feedstock for high-quality steel and chemical production.

Future work should focus on the industrial scaling of column-type flotation units and the refinement of solvent extraction methods to process the resulting foam products into high-purity metal concentrates.

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