ABSTRACT

of the dissertation submitted for the degree of Doctor of Philosophy (PhD) in the specialty 8D07202 – "Metallurgy"

by Kassymova Dinara Bekzhanovna,

"STUDIES ON REDUCING THE NEGATIVE IMPACT OF COPPER-CONTAINING COMPONENTS ON THE PERFORMANCE OF CYANIDE LEACHING OF GOLD-BEARING ORES"

Relevance of the topic. The modern mining industry is forced to work with increased mineralogical complexity of ores and a decrease in the average grade of ore bodies, which makes previously unprofitable deposits economically significant. Under such conditions, the frequent coexistence of gold and copper minerals within a single ore mass creates serious technological and economic obstacles for the traditional cyanide technology of gold extraction. Copper in various mineralogical forms (oxides, sulfides, etc.) is capable of actively consuming available free cyanide through the formation of stable complex compounds, which leads to a significant increase in reagent consumption, reduced gold recovery, and increased operating costs. In addition to direct economic losses, the presence of soluble copper causes a number of related technological problems: competition with gold for adsorption on activated carbon, reduction in the efficiency of electrolytic gold precipitation, possible cementation of gold on the surfaces of copper-containing minerals, and an increase in the volume and complexity of tailings solution treatment. These effects occur even at relatively low concentrations of cyanide-soluble copper, making early and accurate mineralogical forecasting and the implementation of adapted methods of ore pre-treatment or conditioning necessary. The relevance of scientific research is associated not only with economic feasibility but also with environmental and regulatory requirements: increased cyanide consumption and the formation of copper-cyanide complex compounds complicate the detoxification of process solutions and increase environmental risks requiring additional costs for detoxification and reclamation. Therefore, the development of technological schemes that make it possible to minimize the interaction of copper with cyanide, effectively extract copper before cyanidation, or return and regenerate cyanide in closed cycles remains a priority task for improving the sustainability and competitiveness of enterprises.

Scientific novelty of the obtained results. In this work:

- The determining role of the textural-structural and morphological features of micrograined (10–44 μm) chalcopyrite aggregates with secondary copper sulfides (bornite, chalcocite, covellite) in the formation of the gold passivation ("screening") effect and the kinetic limitation of its dissolution process due to competing complex formation of labile copper has been proven.

- Physicochemical regularities of the distribution of ionic forms of copper and sulfur in alkaline cyanide media have been established, substantiating the mechanism of copper ion removal from circulating process solutions without the introduction of

additional sulfidizers, thereby ensuring a synergistic effect of reducing the accumulation of undesirable salt impurities in recycled water.

- A fundamental relationship between the electrochemical potentials of conjugated gold and copper phases in the presence of non-destructive ligands has been identified, establishing the thermodynamic boundaries of selective leaching of the noble metal in the presence of isomorphic and labile copper-containing minerals.

- The thermodynamic limitations of the use of strong oxidizing agents (bleaching powder, sodium hypochlorite) for the destruction of stable copper-cyanide complexes, caused by the formation of intermediate metastable phases, have been kinetically substantiated.

- A methodology for intelligent modeling of nonlinear heterogeneous processes in gold hydrometallurgy based on the probabilistic-deterministic approach and adaptive boosting algorithms (AdaBoost) has been developed, allowing the approximation and prediction of parameters of transient sulfidization regimes and residual copper concentration with increased accuracy (by 2–2.5 times).

The purpose of the dissertation work is to develop an efficient modernized technology for sorption leaching of gold-copper ores aimed at increasing gold recovery with the production of a by-product commercial copper product.

Provisions submitted for defense:

1. The regularity of the decrease in cyanidation performance of gold-copper ores determined by the micrograined nature (10–44 μm) and high degree of aggregation of chalcopyrite with secondary labile copper sulfides (bornite, chalcocite, covellite), which govern the kinetics of gold dissolution due to its screening and competing complex formation.
2. A predictive mathematical model and process control algorithm for copper precipitation from process solutions based on the integration of the probabilistic-deterministic approach and ensemble machine learning (AdaBoost), ensuring a twofold reduction in the approximation error of transient sulfidization regimes under conditions of unstable material composition of the processed raw materials.
3. A physicochemically substantiated technology for copper precipitation in the form of sparingly soluble CuCN, ensuring copper removal from sorption cyanidation solutions while simultaneously reducing the salt load on the recycled water supply system.
4. An integrated closed-loop technological scheme for the hydrometallurgical processing of gold-copper ores from the “Yubileynoye” deposit, distinguished by the combination of precise copper precipitation and deep destruction of residual cyanides using sodium salts, ensuring integrated recovery of gold and copper into commercial products in compliance with environmental standards.

Practical significance of the work – a technology for the hydrometallurgical processing of gold-copper ore from the “Yubileynoye” deposit with the production of an additional commercial copper product has been developed and successfully pilot-tested.

Approbation of the work: a utility model patent of the Republic of Kazakhstan entitled “Method for Copper Precipitation from Recycled Cyanide Solution” has been obtained.

The main scientific results of the dissertation work are presented in six publications issued in the Republic of Kazakhstan and abroad:

1. Kassymova D.B., Adilkanova M.A., Kokaeva G.A., Mamyachenkov S.V., Kushakova L.B. Study of the mineralogical composition of gold-bearing ore from a Kazakhstan deposit // Bulletin of D. Serikbayev East Kazakhstan State Technical University – 2019 – No. 3 – pp. 28–35.

2. Kassymova D.B., Adilkanova M.A., Mamyachenkov S.V., Sizikova N.V. Methods for selective separation of gold and copper during processing of gold-bearing raw materials with high copper content // Bulletin of D. Serikbayev East Kazakhstan State Technical University – 2020 – No. 4 – pp. 36–40.

– including three articles published in editions recommended by CCSES MES RK:

3. Kassymova D.B., Sapinov R.V., Kulenova N.A., Adilkanova M.A. Study of the material composition of gold-copper ores from Kazakhstani deposits // Science and Technology of Kazakhstan – 2025 – No. 1 – pp. 248–258.

4. Kassymova D.B., Sapinov R.V., Adilkanova M.A. Selection of optimal cyanide leaching modes for gold from ore deposits in the Republic of Kazakhstan // Science and Technology of Kazakhstan – 2025 – No. 3 – pp. 257–266.

5. Kassymova D.B., Sapinov R.V., Adylkanova M.A., Reutova G.A. Study of sorption and desorption processes of gold and copper in solutions obtained by cyanide direct leaching with high copper content // Bulletin of D. Serikbayev EKTU. – 2025. – No. 4. – pp. 36–40.

6. Sapinov R.V., Kassymova D.B. Predicting optimal copper precipitation parameters in the cyanidation process for gold-copper ores: from experimental design to adaboost modeling // Science and technology of Kazakhstan. – 2026. – № 3 (в печати).

– an article in a journal included in the Scopus database (Q2, percentile 60) and WoS database (Q2):

1. Kassymova, D.; *Sapinov, R.; Kushakova, L.; Kulenova, N.; Shoshay, Z.; Adylkanova, M. Optimization of Copper Recovery from Cyanide Leaching Solutions Used in Gold–Copper Ore Processing Using Probabilistic–Deterministic Experimental Design. Processes 2025, 13, 61.

A utility model patent of the Republic of Kazakhstan “Method for Copper Precipitation from Recycled Cyanide Solution” was obtained.

The main results were reported at two international conferences:

1. Study of the practice of industrial processing of gold-bearing ores from Kazakhstan deposits with high copper content // Proceedings of the scientific-practical conference “Innovations in Natural Sciences as the Basis for Export-Oriented Industrialization of Kazakhstan”. Almaty, 2019. – pp. 367–370.

2. Study of the features of the method for processing gold-copper ores depending on the content and forms of occurrence of copper // Proceedings of the international conference “Plaksin Readings – 2019”. Problems and prospects of efficient processing of mineral raw materials in the 21st century. Irkutsk, 2019. – pp. 72–74.

Structure and scope of the dissertation.

The dissertation consists of an introduction, 4 sections, a conclusion, and 5 appendices. The work is presented on 136 pages of typewritten text and contains 40 tables and 37 figures. The list of references includes 125 titles.