ABSTRACT

of the dissertation for the degree of Doctor of Philosophy (PhD) in the specialty 8D05302 – «Chemistry»

Abikak Yerkezhan Baimuratkyzy

«Development of technology for the production of non–ferrous and precious metals in the complex processing of man-made waste - pyrite cinders»

Work General characteristics. The dissertation is devoted to the development of technology for obtaining non-ferrous and precious metals during the complex processing of man-made waste – pyrite cinders. Based on the patent information analysis of existing methods of complex processing of pyrite cinders, including as gold-containing raw materials, a hydrometallurgical direction for their processing has been determined. The conducted studies of the material composition of pyrite cinders revealed the need for preliminary magnetic separation with the allocation of a rich magnetic fraction and its activation, which was provided for in the process flow chart. The developed process flow chart for complex processing of the magnetic fraction at the first stage includes sulfuric acid leaching with the extraction of non-ferrous metals and obtaining their concentrate. As a result of subsequent processing of the leaching cake, precious metals were extracted using the developed method of sulfuric acid-thiourea leaching in the presence of an oxidizer. Experiments with the determination of the optimal mode and the influence of process factors were carried out based on the response surface methodology. For the utilization of the resulting industrial products, the technology provides for the production of cast iron, iron oxide pigments and potassium sulfate.

Topic relevance. One of the most important tasks of Kazakhstan's economic development at the present stage is the increase in gold production. This is due to the fact that gold production and international trade are key drivers of sustainable economic growth both for our republic and for many countries around the world. The strategic importance of gold lies in its status as a universal equivalent, as well as its role as an insurance and reserve asset that ensures the ability to make payments in any national currency. This is particularly relevant in light of the consistent increase in the value of gold in recent years.

As industrial sectors that actively use gold and its alloys expand and modernize, there is a significant increase in the demand for this precious metal. At the same time, global reserves of high-quality gold-bearing raw materials are steadily declining. In this context, the development and implementation of innovative technologies for processing gold-bearing materials is of paramount importance for both Kazakhstan’s non-ferrous metallurgy industry and the global industry as a whole. A major unresolved issue in the gold mining industry remains the expansion

of the raw material base, including the processing of man-made gold-containing waste.

In today's world, there is a significant volume of man-made and secondary waste containing gold. Each type of such raw material requires an individual approach to the extraction of precious metals, taking into account the specific chemical composition and form of occurrence.

Unlike other types of man-made waste, metallurgical production waste is exposed to aggressive chemicals and high temperatures. As a result, its chemical composition can differ significantly from that of the original ores. One of the most common types of gold-containing waste is pyrite cinders. These are the by-products of roasting pyrite concentrates used in sulfuric acid production. The influence of atmospheric precipitation and climatic factors on the accumulation of such waste leads to the transformation of their chemical and phase composition. As a result of these processes, soluble compounds of heavy metals, including highly toxic ones, are formed, posing a serious threat to the environment.

On one hand, the accumulation of pyrite cinders presents a real risk of contamination of water and air resources. On the other hand, they are a potential source of ferrous, non-ferrous, and precious metals that are currently underutilized due to the absence of economically viable processing technologies. Therefore, the development of a rational technology for processing pyrite cinders to extract precious, ferrous, and non-ferrous metals is highly relevant, as it will improve the environmental situation in the region, increase the gold and currency reserves of the country, provide additional production of non-ferrous and ferrous metals, and allow the application of developed methods and techniques to the processing of similar man-made waste.

The work aim is development of technology for obtaining non-ferrous and precious metals through the complex processing of pyrite cinders.

To achieve this goal, it is necessary to solve the following main **tasks**:

- analysis of existing scientific, technical and patent information and selection of research directions for the development of processing technology;
- physical and chemical studies of the mineral composition of the pyrite cinders from Tselinny Mining and Chemical Plant;
- determination of optimal conditions for preliminary chemical activation of pyrite cinders;
- carrying out sulfuric acid leaching to obtain a non-ferrous metal concentrate;
- study of the comparative possibility of extracting precious metals by methods of pulp hydrochlorination, thiosulfate leaching and electrochlorination;
- development of a method and optimization of the mode of sulfuric acid-thiourea leaching of precious metals in the presence of an oxidizer using the response surface methodology and large-scale laboratory testing of the technology.

The results of the conducted research and development work and large-scale laboratory tests of the developed technology will serve as the basis for the

development of technological regulations and technical and economic calculations for the project for the production of complex processing of software.

Study object – pyrite cinders are a product of the sulfuric acid production of the Tselinny Mining and Chemical Plant in Stepnogorsk.

Research subject - chemical activation and hydrometallurgical extraction of non-ferrous and precious metals.

Research methods. The work used chemical, X-ray fluorescence, X-ray phase, IR spectroscopic, thermogravimetric, electron microscopic, and atomic absorption methods of analysis.

All studies of this work were carried out on modern experimental equipment of JSC Institute of Metallurgy and Ore Beneficiation.

Work scientific novelty:

-for the first time, to enhance the efficiency of mineral phase exposure in pyrite cinders, a method of preliminary chemical activation in a sodium bicarbonate solution was proposed, carried out under optimal conditions: $NaHCO_3$ concentration – 60 g/dm³, solid-to-liquid ratio (S:L) = 4:1, temperature -120 °C, duration – 60 minutes, ensuring phase transformation of the mineral composition.;

- the possibility of extracting precious metals from pyrite cinders by the method of pulp electrochlorination was investigated under the following conditions: current density -1000 A/m³, duration — 7 hours, and NaCl concentration – 150 g/dm³;

- the feasibility of effective extraction of precious metals from pyrite cinders by thiosulfate leaching using a complex reagent with the following composition (g/dm³): Na_2SO_3 – 100, $Na_2S_2O_3$ – 50, $CuSO_4$ – 2.5 was established;

-a mathematical model of sulfuric acid–thiourea leaching was developed using the response surface methodology, revealing a positive influence of thiourea concentration and leaching duration on the extraction rate of gold and silver.;

- a method for processing pyrite cinders was developed, which includes leaching pulp in a sulfuric acid solution of thiourea (concentration - 3 g/dm³) in the presence of ferric iron salts at pH = 1.8, temperature – 25 °C, and solid-to-liquid ratio (S:L) = 8:1. The developed method is protected by a utility model patent: "Method for Processing Pyrite Cinders" (No. 8178, published on 16.06.2023).;

- based on laboratory and semi-industrial tests conducted at the pilot plant of JSC “IMOB,” results were obtained that enable the development of a technological regulation and a technical and economic justification for pyrite cinder processing.

The main provisions submitted for protection:

- Optimal conditions for the preliminary chemical activation of pyrite cinders have been determined, under which phase transformation occurs – $NaHCO_3$ concentration of 60 g/dm³, liquid-to-solid ratio of 4:1, duration of 60 minutes, and temperature of 120°C;

- during electrochlorination at a current density of 1000 A/m³ in a NaCl solution (concentration – 150 g/dm³) for 7 hours, the extraction rate of gold and silver from pyrite cinders into the solution is 89.7% and 41.1%, respectively;

- during thiosulfate leaching of precious metals from pyrite cinders using a complex reagent with the following composition (g/dm³): Na_2SO_3 - 100, $Na_2S_2O_3$ - 50, $CuSO_4$ - 2.5, the gold extraction rate is 87.2%, and silver - 75.1%;

- the highest efficiency is achieved by the sulfuric acid-thiourea leaching method of precious metals from pyrite cinders in the presence of an oxidizing agent $Fe_2(SO_4)_3$, with parameter optimization using surface response methodology.

Scientific and practical significance. The obtained results of theoretical and experimental studies provide new, deeper insights into the technologies of extracting ferrous, non-ferrous and precious metals from finely dispersed raw materials with complex phase and mineral composition, which will enrich science with new data. This work has important practical significance, since the technology of complex processing of pyrite cinders pursues the goal of increasing the volume of production of non-ferrous and precious metals, but also solves environmental problems associated with their storage.The developed method for processing pyrite cinders is protected by patents of the Republic of Kazakhstan for the utility model "Method for processing pyrite cinders" (utility model No. 8178 dated 16.06.2023) and "Method for leaching polymetallic raw materials" (No. 9913 dated 13.12.2024).

Connection of work with scientific-research projects. The dissertation takes into account the results of research carried out within the framework of the grant-funded project «Development of a technology for processing pyrite cinders with the extraction of valuable components and preliminary chemical activation of the raw material» (contract No. 126/36-21-23 dated April 6, 2021).

Author personal contribution. The author's personal contribution consists of: conducting a patent information search; setting up laboratory experiments; participating in large-scale laboratory tests; constructing a mathematical model of a process of sulfuric acid-thiourea leaching of precious metals using the response surface methodology; selecting and preparing samples for analysis; the formulation of the problem, analysis of the obtained results and formulation of the main conclusions were carried out jointly with scientific consultants.

The degree of reasonableness and reliability of the results obtained in the work is provided by: The validity and reliability of the results are ensured by the fact that proven standard research methods and modern precise measuring devices and installations were used in obtaining them, the volume and statistics of experimental data and their comparison with previously obtained experimental results of famous scientists from the CIS and far abroad. The research results are published in scientific journals.

Approbation of the work results: The main results were reported at the XIV International Conference "Metallurgy of Non-Ferrous, Rare and Noble Metals" dedicated to the 40th anniversary of the Institute of Chemistry and Chemical Technology of the Siberian Branch of the Russian Academy of Sciences. Krasnoyarsk, Russia, September 6, 2021.

Publications: On the topic of the dissertation, 7 printed works were published in co-authorship, of which: 4 articles were published in journals included in the Scopus and Web of Science databases; 1 article was published in a journal recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan and 2 patents for a utility model of the Republic of Kazakhstan.

Structure and volume of the dissertation. The work consists of an introduction, six sections, a conclusion and a list of references. It is presented on 115 pages, contains 55 figures, 31 tables and a list of references from 127 titles.