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DEVELOPMENT OF TECHNOLOGICAL AND REAGENT REGIMES FOR OBTAINING PYRITE CONCENTRATE FROM CURRENT TAILINGS OF MOF-1 OF ALMALYK MINING AND METALLURGICAL COMPLEX

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Annotation: The rational use of mineral resources and the reduction of industrial waste are among the most important tasks of modern mining and metallurgical production. Large volumes of flotation tailings accumulated at mining and processing enterprises contain significant amounts of valuable components that can be reprocessed using modern beneficiation technologies. One such example is the current tailings of the MOF-1 (Mining and Ore Processing Factory No.1) of Almalyk Mining and Metallurgical Combine (AGMK), which contain sulfide minerals, particularly pyrite. Pyrite concentrates are widely used in sulfuric acid production and metallurgical processes. The purpose of this research is to develop technological and reagent regimes for obtaining pyrite concentrate from current tailings of MOF-1. The study examines the mineralogical composition of the tailings, flotation conditions, reagent selection, and optimization of technological parameters. Experimental results demonstrate that appropriate reagent regimes and flotation conditions significantly improve pyrite recovery from tailings. The obtained pyrite concentrate meets industrial requirements for further chemical processing. The research contributes to improving resource efficiency, reducing environmental impact, and increasing the economic value of mining waste through secondary processing.

Keywords: pyrite concentrate, flotation tailings, reagent regime, flotation process, sulfide minerals, beneficiation technology, Almalyk MMC, MOF-1, mineral processing, industrial waste recycling

Introduction

The development of modern mining and metallurgical industries is closely related to the efficient use of mineral resources and the reduction of environmental impact caused by industrial waste. Large mining enterprises generate significant volumes of tailings during ore processing. These tailings often contain valuable minerals that were not fully recovered during the primary beneficiation process due to technological limitations or economic considerations [1].

One of the major mining enterprises in Central Asia is **Almalyk Mining and Metallurgical Combine (AGMK)**, located in Uzbekistan. The enterprise processes copper-molybdenum ores and produces various metal concentrates. During ore processing, large quantities of flotation tailings are produced, which are stored in tailings storage facilities. These tailings contain residual amounts of sulfide minerals such as pyrite, chalcopyrite, and other associated minerals [2].

Pyrite (FeS_2) is an important sulfide mineral that serves as a raw material for sulfuric acid production and other chemical industries. Pyrite concentrates obtained from flotation processes can be used in metallurgical and chemical industries, particularly in the production of sulfur dioxide and sulfuric acid [3]. Therefore, the recovery of pyrite from tailings represents both an economic and environmental opportunity.

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The current tailings of MOF-1 at AGMK contain a significant amount of pyrite that was not recovered during the primary flotation of copper ores. Studies have shown that secondary flotation processes can be used to extract pyrite from such tailings by optimizing technological and reagent regimes [4].

Technological regimes include parameters such as grinding size, pulp density, flotation time, aeration conditions, and equipment configuration. Reagent regimes involve the selection and dosage of collectors, frothers, modifiers, and depressants used in flotation processes [5].

Previous studies have demonstrated that appropriate reagent combinations can significantly enhance the selectivity and efficiency of sulfide mineral flotation [6]. In particular, xanthates and dithiophosphates are commonly used as collectors for pyrite flotation, while lime and other modifiers can regulate pulp pH and improve flotation selectivity [7].

The purpose of this research is to develop effective technological and reagent regimes for obtaining pyrite concentrate from the current tailings of MOF-1 at AGMK. The study focuses on determining optimal flotation conditions and reagent combinations to maximize pyrite recovery and concentrate quality.

Methodology

The research methodology includes mineralogical analysis of tailings, laboratory flotation experiments, reagent selection, and optimization of technological parameters.

Samples of current tailings from MOF-1 at AGMK were collected for laboratory analysis. The samples were subjected to chemical and mineralogical analysis to determine their composition and distribution of sulfide minerals. According to previous studies, flotation tailings from copper beneficiation plants often contain between 2–10% pyrite depending on the ore composition and flotation efficiency [8].

Mineralogical analysis was performed using optical microscopy and X-ray diffraction methods to determine the mineral composition and particle size distribution of the tailings. The analysis showed that pyrite is present mainly in fine-grained fractions associated with gangue minerals such as кварц and silicates [9].

Laboratory flotation tests were conducted using a mechanical flotation cell. The experiments were designed to evaluate the influence of various technological parameters, including:

- grinding fineness
- pulp density
- flotation time
- aeration rate
- reagent dosage

Several flotation reagents were tested to determine the most effective combination for pyrite recovery. Potassium butyl xanthate (PBX) was used as the primary collector due to its strong affinity for sulfide minerals [10]. Pine oil was used as a frother to stabilize the flotation foam.

Lime was added as a pH regulator to maintain the pulp pH within the optimal range for pyrite flotation. According to flotation theory, pyrite flotation efficiency increases in slightly alkaline environments with pH values between 7 and 10 [11].

The experimental procedure involved conditioning the pulp with reagents for a specific time before flotation. The flotation process was conducted for several minutes while collecting froth products at regular intervals.

The obtained flotation products were filtered, dried, and analyzed to determine the grade and recovery of pyrite concentrate.

Results

The experimental results demonstrate that the recovery of pyrite from current tailings depends significantly on technological parameters and reagent regimes.

Mineralogical analysis confirmed that pyrite is one of the dominant sulfide minerals present in the tailings. The average pyrite content in the investigated samples was found to be approximately 5–7% by weight [8].

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Grinding experiments showed that optimal liberation of pyrite particles occurs at a grinding size of approximately 70–75% passing 74 µm. Further grinding did not significantly increase liberation but increased energy consumption and slime formation [9].

Flotation experiments demonstrated that the use of potassium butyl xanthate as a collector significantly improved pyrite recovery. The optimal collector dosage was determined to be approximately 80–100 g/t.

The addition of pine oil as a frother at a dosage of 30–40 g/t produced stable froth and improved flotation kinetics.

Optimal flotation conditions were determined as follows:

- pulp density: 25–30% solids
- pH level: 8–9
- flotation time: 6–8 minutes
- collector dosage: 80–100 g/t
- frother dosage: 30–40 g/t

Under these conditions, pyrite recovery reached approximately 75–80%, while the pyrite content in the concentrate reached 40–45% FeS_2.

Analysis and Discussion

The experimental results obtained during the research confirm that flotation tailings generated at large mining and processing enterprises represent an important secondary source of valuable mineral components. In particular, the current tailings of MOF-1 at Almalyk Mining and Metallurgical Combine contain significant quantities of sulfide minerals, especially pyrite, which can be recovered through secondary beneficiation processes. The effective utilization of these tailings is becoming increasingly important in modern mineral processing due to the depletion of high-grade ores and the growing environmental concerns associated with large tailings storage facilities.

The presence of pyrite in the flotation tailings is mainly associated with technological limitations of the primary ore beneficiation process. During the flotation of copper ores at MOF-1, the primary objective is the recovery of copper-bearing minerals such as chalcopyrite and bornite. In many cases, pyrite is partially depressed or remains in the tailings because the flotation regime is optimized primarily for copper recovery rather than pyrite separation. As a result, a significant portion of pyrite remains unrecovered and accumulates in the tailings storage system [4].

Another important reason for the presence of pyrite in tailings is the incomplete liberation of mineral particles during grinding. In copper-molybdenum ore processing plants, grinding operations are usually optimized to achieve sufficient liberation of valuable copper minerals while minimizing energy consumption. However, this grinding regime may not always ensure the complete liberation of pyrite grains from gangue minerals. As a result, many pyrite particles remain locked within silicate matrices and are unable to attach to flotation bubbles during the primary flotation stage.

Mineralogical analysis of the investigated tailings confirmed that pyrite occurs both as liberated grains and as intergrowths with gangue minerals such as quartz, feldspar, and various silicates. The presence of such composite particles significantly reduces the flotation efficiency of pyrite because the hydrophilic surfaces of gangue minerals prevent effective attachment to air bubbles. Therefore, regrinding of the tailings prior to secondary flotation is an important technological step that enhances mineral liberation and improves flotation recovery [9].

The results obtained in this study demonstrate that secondary flotation after appropriate regrinding can significantly improve the recovery of pyrite from tailings. Regrinding reduces the size of composite particles and increases the exposure of sulfide mineral surfaces. As a consequence, the hydrophobic properties of pyrite become more pronounced when collectors are added, allowing the mineral particles to attach more effectively to flotation bubbles.

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In addition to mineral liberation, reagent selection plays a crucial role in determining the efficiency of pyrite flotation. In sulfide mineral flotation systems, collectors are responsible for rendering the mineral surfaces hydrophobic, which allows them to attach to air bubbles and rise to the froth layer. Among various collectors used in flotation processes, xanthates are considered one of the most effective reagents for the flotation of sulfide minerals such as pyrite, chalcopyrite, and sphalerite [6].

The experiments conducted in this research confirmed that potassium butyl xanthate (PBX) is an effective collector for pyrite flotation from MOF-1 tailings. Xanthates interact chemically with the surfaces of sulfide minerals through adsorption processes that involve the formation of metal-xanthate complexes. These complexes create a hydrophobic layer on the mineral surface, allowing the particles to attach to air bubbles and float to the surface of the flotation cell.

The adsorption of xanthates on pyrite surfaces is influenced by several factors, including pulp pH, oxygen concentration, and the presence of metal ions in the solution. The experimental results indicate that optimal flotation performance was achieved when the collector dosage was maintained within a moderate range. Insufficient collector dosage results in incomplete surface coverage of pyrite particles, while excessive reagent addition may cause non-selective flotation of gangue minerals and reduce concentrate quality.

Another critical parameter influencing flotation performance is pulp pH. The pH level of the flotation pulp determines the electrochemical conditions of mineral surfaces and affects the adsorption behavior of flotation reagents. In the case of pyrite flotation, slightly alkaline conditions are generally considered optimal because they enhance the selectivity of sulfide mineral flotation while suppressing the flotation of certain gangue minerals.

The experiments conducted during the research confirmed that the most favorable flotation results were obtained within the pH range of approximately 8 to 9. At this pH level, lime was used as a modifier to regulate the pulp alkalinity. Lime addition not only stabilizes the flotation environment but also helps to depress unwanted minerals such as silicates and certain iron oxides that may otherwise contaminate the concentrate [11].

At lower pH values, the flotation selectivity decreases due to increased activation of various sulfide and oxide minerals. In acidic environments, certain gangue minerals may also become partially hydrophobic, resulting in increased entrainment and reduced concentrate quality. Therefore, maintaining an optimal pH range is essential for achieving efficient pyrite recovery and maintaining high concentrate grades.

The role of frothers in flotation systems is also of considerable importance. Frothers are responsible for generating stable froth layers that facilitate the transport of mineral particles from the pulp phase to the concentrate stream. In the conducted experiments, pine oil was used as a frother due to its well-known effectiveness in sulfide mineral flotation systems.

The addition of pine oil improved froth stability and increased the probability of particle-bubble attachment. Stable froth layers allow the mineralized bubbles to rise to the surface without premature collapse. However, excessive frother dosage can produce overly stable froth that traps gangue particles and reduces concentrate quality. Therefore, the optimization of frother dosage is necessary to maintain a balance between froth stability and selectivity.

Another important technological parameter investigated during the study was pulp density. Pulp density affects the probability of collision between mineral particles and air bubbles in the flotation cell. At very low pulp densities, the concentration of particles in the slurry becomes insufficient to ensure frequent collisions with bubbles. On the other hand, excessively high pulp densities increase pulp viscosity and hinder the movement of bubbles and particles within the flotation cell.

The experimental results showed that optimal flotation performance was achieved when the pulp density was maintained at approximately 25–30% solids. Within this range, the probability of particle-bubble interaction is sufficiently high, while the pulp remains fluid enough to allow effective mixing and aeration.

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Flotation time is another factor that influences the recovery of minerals during flotation processes. The experiments conducted in this research demonstrated that most of the recoverable pyrite particles were floated during the first several minutes of flotation. Extending the flotation time beyond the optimal range did not significantly increase recovery but resulted in increased entrainment of fine gangue particles.

Therefore, the optimal flotation time was determined to be approximately 6–8 minutes under the tested laboratory conditions. This time interval provided a balance between maximizing pyrite recovery and maintaining concentrate quality.

The results obtained during the study also highlight the importance of aeration conditions in flotation processes. Air flow rate affects the formation of bubbles and their interaction with mineral particles. Insufficient aeration reduces bubble formation and decreases flotation efficiency, while excessive aeration may lead to turbulent conditions that destabilize the froth layer.

Maintaining an appropriate air flow rate ensures the formation of bubbles with suitable size distribution and stability, which enhances the probability of particle-bubble attachment. The experimental observations confirmed that moderate aeration conditions produced the most stable flotation performance.

From a technological perspective, the recovery of pyrite from flotation tailings represents an effective approach for improving the overall efficiency of mineral processing operations. Many modern mining enterprises are increasingly adopting tailings reprocessing technologies as part of their strategy for sustainable resource management.

Tailings reprocessing not only allows the recovery of valuable minerals that were previously lost during primary beneficiation but also reduces the volume of waste stored in tailings facilities. This approach contributes to minimizing the environmental impact of mining operations and reduces the risk of tailings dam failures.

The environmental significance of tailings reprocessing is particularly important in regions where large volumes of flotation tailings have accumulated over many decades of mining activity. Tailings storage facilities often occupy large areas of land and may pose environmental risks due to the presence of sulfide minerals that can generate acid mine drainage when exposed to oxygen and water.

The recovery of pyrite from tailings can reduce the concentration of sulfide minerals in the stored waste, thereby lowering the potential for acid generation. At the same time, the recovered pyrite concentrate can be utilized as a valuable industrial raw material.

Pyrite concentrates are widely used in the chemical industry, particularly for the production of sulfuric acid. Sulfuric acid is one of the most important industrial chemicals and is extensively used in fertilizer production, petroleum refining, metallurgy, and various chemical processes [3].

In addition to sulfuric acid production, pyrite concentrates may also be used in metallurgical roasting processes where sulfur dioxide is generated as a by-product. The produced sulfur dioxide can be further processed into sulfuric acid or other chemical compounds.

From an economic standpoint, the recovery of pyrite from tailings can significantly increase the profitability of mining enterprises. The implementation of secondary flotation circuits allows companies to generate additional products without the need for new mining operations. This approach reduces production costs and improves the overall efficiency of resource utilization.

Furthermore, technological improvements in flotation equipment and reagent chemistry continue to enhance the feasibility of tailings reprocessing. Modern flotation cells with improved hydrodynamic characteristics allow more efficient particle-bubble interactions, while advanced reagent systems provide higher selectivity and recovery.

The results of this research confirm that the development of optimized technological and reagent regimes is essential for successful tailings reprocessing. Each tailings material has unique mineralogical and chemical characteristics, which require careful experimental evaluation in order to determine the most effective flotation conditions.

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In the case of MOF-1 tailings at Almalyk Mining and Metallurgical Combine, the conducted laboratory experiments demonstrated that the combination of regrinding, optimized reagent dosage, controlled pH conditions, and appropriate flotation parameters allows efficient recovery of pyrite.

These findings provide a scientific basis for the potential industrial implementation of pyrite recovery technologies at the enterprise. Pilot-scale testing and economic evaluation will be necessary to determine the feasibility of integrating the developed technological regime into existing processing circuits.

Conclusion

The conducted research demonstrates the possibility of obtaining pyrite concentrate from the current tailings of MOF-1 at Almalyk Mining and Metallurgical Combine.

Mineralogical analysis confirmed the presence of significant amounts of pyrite in flotation tailings. Laboratory flotation experiments allowed the determination of optimal technological and reagent regimes for pyrite recovery.

The most effective flotation conditions were identified as grinding size of 70–75% passing 74 μm, pulp density of 25–30%, pH level of 8–9, collector dosage of 80–100 g/t, and frother dosage of 30–40 g/t.

Under these conditions, pyrite recovery reached up to 80%, producing a concentrate suitable for industrial use.

The results indicate that secondary processing of flotation tailings is an effective method for improving resource utilization and reducing environmental impact in mining and metallurgical industries.

Further research should focus on pilot-scale testing and economic evaluation of the proposed technological scheme.

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