PROCESS MINERALOGY STUDY AND FLOTATION TESTWORK OF A COMPLEX LEAD-GOLD ROUGHER CONCENTRATE

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ABSTRACT

A lead–gold rougher concentrate was studied to investigate the efficiency of mineral processing. Using process mineralogy as the guiding theory, mineralogical parameters such as chemical composition, mineral composition, mineral particle size, and symbiotic association between minerals were studied in detail. A systematic lead flotation testwork program was carried out to obtain the optimal flotation and separation conditions, and the products obtained were analyzed. The results show that the concentrate contains a wide variety of minerals with complex material composition, and the lead mineral was mainly galena with a relative content of 3.43% and a particle size −37 μm accounting for 94.72%, while the gold minerals were dominated by electrum. The grades of gold, silver, and lead in the balland obtained through the flotation closed-circuit test were 512.10 g/t, 1632.80 g/t, and 40.38%, and the recoveries were 70.65%, 73.86%, and 75.37%, respectively. The gold lost in the flotation tailings was mainly dominated by gold encapsulated in metal sulfide (accounting for 55.67%), and the lead lost was mainly in gangue and metal oxides (accounting for 62.72%).

Keywords: process mineralogy; lead–gold polymetallic rougher concentrate; flotation; mineral liberation and enclosure characteristics; metal recovery

ПРОЦЕССИВНОЕ МИНЕРАЛОГИЧЕСКОЕ ИССЛЕДОВАНИЕ И ФЛОТАЦИОННОЕ ТЕСТИРОВАНИЕ КОМПЛЕКСНОГО КОНЦЕНТРАТА СВИНОЧНО-ЗОЛОТНОГО РУДНИКА

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АННОТАЦИЯ:

Для изучения эффективности переработки полезных ископаемых был исследован свинцово-золотой грубый концентрат. Используя технологическую минералогию в качестве руководящей теории, были детально изучены такие минералогические параметры, как химический состав, минеральный состав, размер минеральных частиц и симбиотическая связь между минералами. Для получения оптимальных условий флотации и сепарации была проведена систематическая программа испытаний свинцовой флотации, а полученные продукты проанализированы. Результаты показывают, что концентрат содержит широкий спектр минералов со сложным вещественным составом, а минералом свинца в основном является гален с относительным содержанием 3,43%, а размер частиц −37 мкм составляет 94,72%; в минералах золота преобладает электрум. Марки золота, серебра и свинца в баллане, полученном флотационным замкнутым испытанием, составили 512,10 г/т, 1632,80 г/т и 40,38%, а извлечение составило 70,65%, 73,86% и 75,37% соответственно. В составе золота, потерянного в флотационных хвостах, преобладали золото,

инкапсулированное в сульфиде металлов (55,67%) и свинец, потерянный в основном в породе и оксидах металлов (62,72%).

КЛЮЧЕВЫЕ СЛОВА: технологическая минералогия; свинцово-золотой полиметаллический грубый концентрат; флотация; характеристики высвобождения и заключения полезных ископаемых; извлечение металла

Introduction

Lead is an important industrial raw material due to its low melting point, high corrosion resistance, and strong X-ray shielding capacity. It is widely used in various industries, including chemical manufacturing and battery production. Gold and silver, as two critical precious metals, not only have broad industrial applications but also serve as vital assets for investment and national reserves. These metals are commonly found in their native states or embedded within the structures of sulfide and silicate minerals, frequently coexisting with minerals such as chalcopyrite, galena, sphalerite, and pyrite. In most flotation plants, gold is often enriched alongside lead, copper, zinc, and pyrite minerals. With the depletion of high-grade, easily processed ore resources, increasing attention in the mining sector has shifted toward the efficient utilization of complex and refractory polymetallic ores. Among these, lead-bearing polymetallic concentrates have become a research focus due to their significant economic potential. These concentrates typically contain lead, gold, silver, and other valuable metals. The efficient separation and enrichment of these metals are not only essential for maximizing economic returns but also play a key role in improving mining efficiency and resource utilization rates. Lead–gold mixed rougher concentrates often exhibit complex compositions. In addition to galena (PbS), they commonly contain pyrite (FeS_2), sphalerite (ZnS), arsenopyrite (As_2S_3), and native gold and silver. The intricate interlocking of these minerals, combined with their diverse physical and chemical properties, poses significant challenges to traditional mineral processing techniques. For instance, lead minerals are often finely disseminated, while gold and silver may occur as ultrafine particles embedded within sulfide minerals, rendering them difficult to recover via single beneficiation methods. Therefore, integrated separation strategies are required .

Depending on the bulk mineralogy and metal deportment, gravity concentration and flotation are often employed prior to chemical treatment. Among them, flotation is the preferred method due to its effectiveness in concentrating and separating fine-grained minerals. However, to optimize flotation performance, a detailed process mineralogical investigation must be conducted in advance to guide reagent selection and parameter settings. As an interdisciplinary field integrating mineralogy, metallurgy, and materials science, process mineralogy has become a powerful theoretical tool for addressing the beneficiation challenges of complex ores. Through systematic analysis of mineral composition, particle size distribution, liberation characteristics, texture, and mineral associations, process mineralogy provides essential data for flowsheet design and optimization. Modern analytical techniques such as mineral liberation analysis (MLA), scanning electron microscopy (SEM), and electron probe microanalysis (EPMA) enable quantitative determination of the occurrence states and interactions of valuable minerals. Such information is critical for guiding the selection and adjustment of beneficiation processes including flotation, gravity separation, roasting, and leaching.

As one of the most commonly and effectively used techniques for treating sulfide ores and their complex counterparts, flotation has been extensively applied in the recovery of galena, gold, and silver minerals. However, flotation efficiency is greatly influenced by factors such as mineral liberation, reagent regimes, and process parameters. Previous studies have demonstrated that a deep understanding of mineral surface chemistry, particle size effects, and interlocking relationships is essential for improving flotation performance. Luo et al. enhanced lead mineral recovery from low-grade lead–zinc ores by raising slurry concentration from 27% to 55%, increased lead recovery from 60% to 80%, and boosted lead grade from 27.5% to 29.1%. Li et al. proposed a synergistic MIBC + kerosene decarburization before flotation to reduce metal loss, and achieved subsequent flotation recoveries of lead and zinc at 87.64% and 94.09%, respectively. Yu et al. conducted detailed mineralogical characterization and flotation optimization on low-grade oxidized lead–zinc ore. Through the study, they clarified the mineral symbiosis and determined an optimal process route, achieving a lead grade of 2.83% with 57.56% recovery, and a zinc grade of 28.64% with 83.45% recovery. Li et al. employed a gold flotation-concentrate leaching lead–zinc flotation process for low-grade refractory ores. This yielded a gold concentrate with an Au concentration of 40.23 g/t and 86.25% recovery, achieving a 98.76% leaching rate, along with effective recovery of lead and zinc.

The complex lead–gold rougher concentrate investigated in this study was derived from a pre-concentration flotation operation and features a complex mineralogical composition. It primarily includes galena, pyrite, arsenopyrite, electrum, and minor amounts of chalcopyrite and sphalerite. Preliminary chemical analysis revealed that the concentrate contained 3.74% Pb, 50.50 g/t Au, and 154.80 g/t Ag, indicating high economic value. However, most of the gold was either embedded in or encapsulated by fine-grained sulfide minerals, posing significant challenges to traditional flotation and leaching technologies.

In this study, a detailed process mineralogical analysis of the Pb–Au concentrate was carried out using X-ray fluorescence spectrometry (XRF), mineral liberation analysis (MLA), and electron probe microanalysis (EPMA) and polarized light microscopy. This work characterized the mineral composition, particle size, and mineral associations of lead, gold, and silver, providing theoretical support for selecting appropriate flotation methods. Systematic flotation experiments were conducted to determine optimal separation conditions. Additionally, exploratory cyanide leaching tests were performed on the flotation concentrate, and the products were thoroughly evaluated. By integrating process mineralogy with flotation techniques, this study proposes a theoretical and technical framework for the efficient utilization of complex Pb–Au rougher concentrates. The findings offer valuable guidance for the comprehensive recovery of similar refractory polymetallic mineral resources and hold significant academic and engineering implications.

2.Experiment

2.1 Materials

2.1.1 Sample

The lead–gold rougher concentrate material, weighing approximately 200 kg, was received from a company in Liaoning. The sample was dried, blended, split, and bagged for the testwork.

2.1.2 Reagent

Activated carbon and sodium sulfide were used as detackifiers; zinc sulfate, sodium thiosulfate, sodium sulfide, and sodium sulfite were used as inhibitors; sulfur, SN9, butyl ammonium black, aniline black, ethyl yellow, isopropyl yellow, and CG1325 as trapping agents; and MIBC as a foaming agent. Sodium cyanide was used as the leaching agent for gold, while sodium carbonate and calcium oxide were used as slurry conditioners. Tap water was used throughout, and all chemicals were sourced from McLean Biochemical Technology Co. (Shanghai, China). All reagents were of analytical grade, and pH modifiers were used as necessary for the reactions.

2.2 Methods

2.2.1. Process Mineralogy Study

Lead, gold, and silver in the raw materials were characterized using a Mineral Liberation Analyzer (Thermo Fisher Scientific, Waltham, MA, USA), Polarizing Microscope (Eclipse LV100POL, Nikon, Tokyo, Japan), Electron Probe Microanalyzer (EPMA JXA-8230, UZONGLAB, Shanghai, China), and Scanning Electron Microscope (Sigma 300, Kefu Mechanical and Electrical Equipment Co., Ltd., Hangzhou, China). Various particle size fractions were analyzed for mineralogical characteristics and mineral liberation. The chemical composition of the sample was analyzed using an X-ray Fluorescence Spectrometer (EDX-7000, Xinyichuang Technology Co., Ltd., Shenzhen, China) and an Inductively Coupled Plasma Spectrometer (PerkinElmerAvio550, PerkinElmer, Shanghai, China).

To analyze the particle size distribution and morphology of gold minerals, heavy mineral concentrates were first obtained through manual panning (gravity concentration). The recovered concentrate was then observed under a polarizing microscope. Gold particles were manually picked and transferred onto glass slides for imaging. Their sizes were measured using a calibrated eyepiece micrometer, and morphological types were recorded and classified based on visual characteristics (e.g., flaky, angular, elongated). A sufficient number of particles were examined to ensure representative statistical data. This manual method was adopted due to the low content and fine-grained nature of the gold particles, and was effective in capturing their liberation state and surface features.

2.2.2. Flotation

The flotation test was conducted by preparing a slurry with 28% solid concentration (comprising 500 g of ore and water) in a plastic bucket. The slurry was stirred using a mechanical stirrer at 400 rpm for 5 min. After mixing, the slurry was quantitatively transferred to a 1.5 L air-inflated flotation cell for testing. Care was taken to prevent sample stratification during transfer. The flotation machine was operated at 1900 rpm. Depending on the test requirements, reagents such as collector, inhibitor, depressant, regulator, and frother were added, and pH monitoring was conducted during the flotation tests. Flotation was performed at room temperature, with a mixing time of 8 min. The flotation concentrates, middlings, and tailings were dried, weighed, and sampled for analysis of the target element grades. The corresponding yields and recoveries were then calculated.

2.2.3. Leaching

Leaching tests were conducted in a 0.5 L conical flask in the magnetic stirring water bath with a slurry concentration of 33%. A 100 g concentrate sample and water were added, followed by pretreatment with calcium oxide for a specified duration.

Sodium cyanide was then added for leaching over a period of 48 h. The leachate and leaching residue were collected. The residue was washed three times before being sent for analysis. The leaching rate (α) was calculated using the following formula: where m_0 and m_t are the ore masses before and after leaching, and w_0 and w_t represent the corresponding metal grades.

$$\alpha=1-m_1 w_1/m_0w_0$$

(1)

Comparative tests analyzed the fluctuation range of recovery and grade for each factor in the flotation condition tests, assessing the impact of these factors on flotation indices. The fluctuation range was calculated as follows:

$$\gamma=\gamma_{max}-\gamma_{min} \quad (2)$$

$$\beta=\beta_{max}-\beta_{min} \quad (3)$$

where γ represents the recovery rate, fluctuation β represents the grade fluctuation, γmax represents the maximum recovery rate of each factor, and γmin represents the minimum recovery rate of each factor. βmax is the maximum grading rate of each factor and βmin is the minimum grading rate of each factor.

2.3 Process flow chart

The process flow chart is presented in **Figure 1**. The complex and refractory lead–gold rougher concentrate underwent rougher flotation to produce a rougher concentrate and rougher flotation tailings. The rougher concentrate was further cleaned to obtain lead concentrate and cleaner tailings. The balland then underwent preliminary cyanide leaching to produce a gold and pregnant solution enriched in silver and leaching residue.

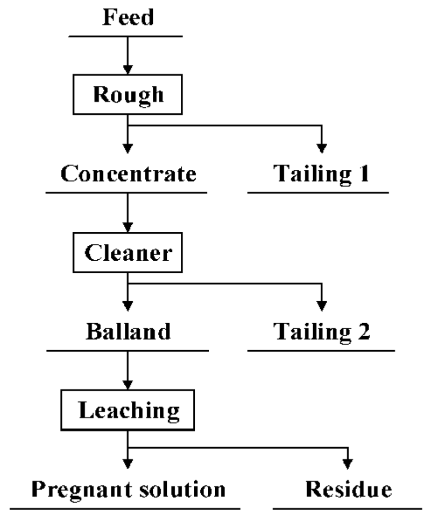

Figure 1. Process flow chart.

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