ОБОГАЩЕНИЕ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

DOI: 10.21440/0536-1028-2021-7-35-44

Developing the technology of associated gold recovery when concentrating copper-pyrite ore

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Abstract

Research objective *is to address an up to date task of developing the technology of associated gold recovery from complex ore.*

Object of research *is the gold-bearing copper-pyrite ore. Gold was recovered in laboratory conditions with the use of gravity methods of mineral separation.*

Research tools. *Rational modes of machinery operation have been determined through mathematical planning of experiments including the obtained results processing by mathematical and statistical methods.*

Methods of research. *Gold was recovered in the grinding-classification circuit based on a series-installed short-cone hydrocyclone, a jigging machine and a shaking table.*

Research results. *The developed jig mode differs from the existing ones by the closed-circuit of jig machine chambers: from the feed of the second (in the direction of the light fraction travel) jig chamber, the light fraction (tailings) and undersize product – fraction with the increased content of accessory minerals (rough concentrate) are separated. The rough concentrate in the second chamber is directed to the first chamber of the machine, where the finished jig concentrate is obtained in the form of an undersize product. The light fraction moves from the first chamber to the second and is removed from the machine through the tail board. When fine-tuning the heavy fraction of jigging on a shaking table, it is recommended to mix 1/2 part of the initial feed of the tables with the rough concentrate isolated from the other 1/2 of the original feed. The new jigging mode and the scheme of concentration on the tables provide an increase in the gold content in the initial feed of the apparatus, which is the reason for a decrease in gold losses with the tails of the gravity circuit.*

Research relevance. *Gold recovery increment by 4.77% was obtained due to the use of all three recommended scientific and technical measures, namely sands concentration in a short head cone crusher on a jig, switching the jig chambers to a closed circuit, and jet motion of concentrates on shaking tables.*

Scope of the results. *The results should be applied when concentrating ore containing free (amalgamable) gold, as well as gold-bearing pyrite.*

Keywords: *copper-pyrite ore; gold; associated extraction; gravity.*

Introduction. This research addresses the task of developing the technology of associated gold recovery. The issue is highly relevant for mining enterprises processing complex copper ore [1]. Return on equity for associated valuable noble metals production turns out to be rather high since 80–90% of all costs are connected with core products manufacture and are outweighed by its gross value [2–4].

Gold recovery into copper concentrates in the course of copper-zinc gold-bearing ore processing in the Urals doesn’t exceed 10–20% under the weight content of noble metal varying from 0.2 to 10 g/t [5]. Only for ores in particular fields, for instance Gaysky and Oktyabrsky, gold recovery makes up 15–45%. Noble metals loss is basically (40–90 %) connected with the pyritic concentrate, since in the course of pyritic Uralian ore processing with the pyritic concentrate, from 10 to 11 t of gold are lost annually [4, 5]. Gold grain surface passivation in the processes of *grinding–classification* and high content of free CaO are other reasons for the loss of gold with tailings [6–10].

The object of this research are typical refractory copper-pyrite ores of the Urupsky field (Karachay-Cherkess Republic). In the course of these ores flotation, gold is extracted as an associated component by gravitational methods of concentration. Gold in ores is mainly accompanied by pyrite [2, 3, 5]. Therefore, with an increase in the copper concentrates quality, gold loss with flotation tailings inevitably increases [5, 11, 12]. In some instances, to increase profit by paying for gold in copper concentrate, its quality during flotation is reduced (for example, down to 15% at JSC Svyatogor). However, the costs of bare concentrate processing at a copper plant are increased significantly [5, 13, 14].

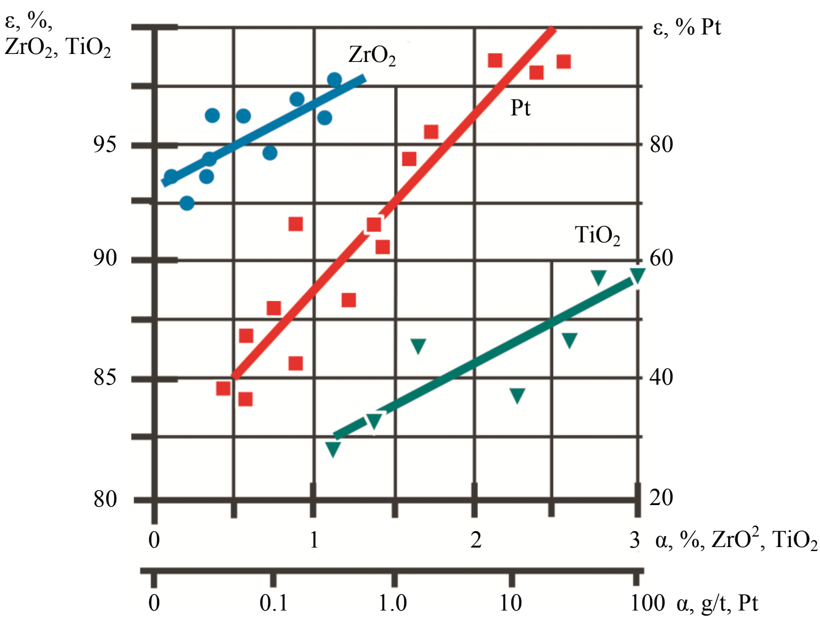

Figure 1. Extracting zirconium dioxide, native platinum, and titanium dioxide depending of their content in placer sand

Рисунок 1. Извлечение диоксида циркония, самородной платины и диоксида титана в зависимости от их содержания в песках россыпи

The technological solutions under discussion. As a database for the development of new modes for mineral separation by density, the dependences between valuable components extraction and their content in the feedstock have been used. They had previously been obtained by a number of researchers [15–24] in the course of concentration by gravity methods (Figure 1) among other things.

High concentration of the valuable component in the feedstock required for its complete extraction can be achieved through the use of rough concentrate dressed from a part of the feedstock in circulation [25–27].

In this research, gold from the mill discharge was recovered on a duplex diaphragm jig machine with jigging concentrate cleaning on a shaking table.

To increase gold recovery, the material was jigged when jig machine chambers were operated in a closed circuit. In this mode, the light fraction of the material transfers from the first chamber to the second and exits the machine through the tail board.

The undersize product of the second (in the direction of the light fraction travel) jig chamber is directed into the first chamber combining it with the original feedstock. A jig concentrate is obtained from the resulting mixture in the form of an undersize product of the first chamber.

When cleaning the jig concentrate, a heavy fraction is separated from its half (1st concentration jet) on shaking tables and combined with another half of the jig concentrate. A commercial gold-bearing gravity concentrate is separated from the resulting blend (2nd concentration jet).

Results and discussion. In the first series of experiments, in the *grinding–classification* circuit, gold was recovered according to the factory scheme, i.e. using a short head cone crusher, the sands of which were cleaned up on a shaking table.

Table 1. Mode and technological indicators of concentration on tables
Таблица 1. Режим и технологические показатели процесса концентрации на столах

Indicator	Process scheme	
	jigging with concentration on the table	jigging (chambers are operated in a closed circuit) with concentration on tables (jet scheme)
Deck table operation mode:		
stroke frequency n, min^{-1}	324	339
stroke length l, mm	6	6
water consumption for flushing q, m^3/t	2.5	2.5
Concnetrate of the table:		
yield, %	0.22	0.37
Au content, g/t	35.93	37.26
Au recovery, %	5.27	9.19
response function	5.15	9.00
concentration grade	3.47	3.58

In the experiment, a short head cone crusher designed by the Central Research Institute of Geological Prospecting for Base and Precious Metals (TsNIGRI) was used with a diameter of 35 mm and a 90° tapering angle of the conical part. Power was supplied by a sand centrifugal pump with a pulp pressure at the inlet of 0.051 MPa through a branch pipe with a 6 mm feed diameter. To separate the sands, a sand nozzle with a 2 mm diameter and an 8 mm diameter of underflow were installed. The specific load on the sand hole was maintained at 1.43 t / (cm^2 · h), the size of the nominal grain in the underflow was 40 μm.

As a result, a heavy fraction containing 34.77 g/t Au was separated on the table, the recovery of which was 5.12%.

Low productivity of shaking tables allows only part of the sands of short head cone crushers to be involved in processing, which reduces the commercial yield. To reduce the amount of sands of short head cone crushers directed for concentration on the tables, a jig machine was used.

Under laboratory conditions, the sands of a short head cone crusher were concentrated on the MOD-0.2 jig machine. The rational mode of jigging was determined by the experiment planning method with four factors variation at two levels. The cones stroke of X_1 ranged within l = 3–7 mm, the vibration frequency of the X_2 cones ranged within n = 200–240 min^{-1}, the flow rate of X_3 undersize water ranged within q = 4–6 m^3/t,

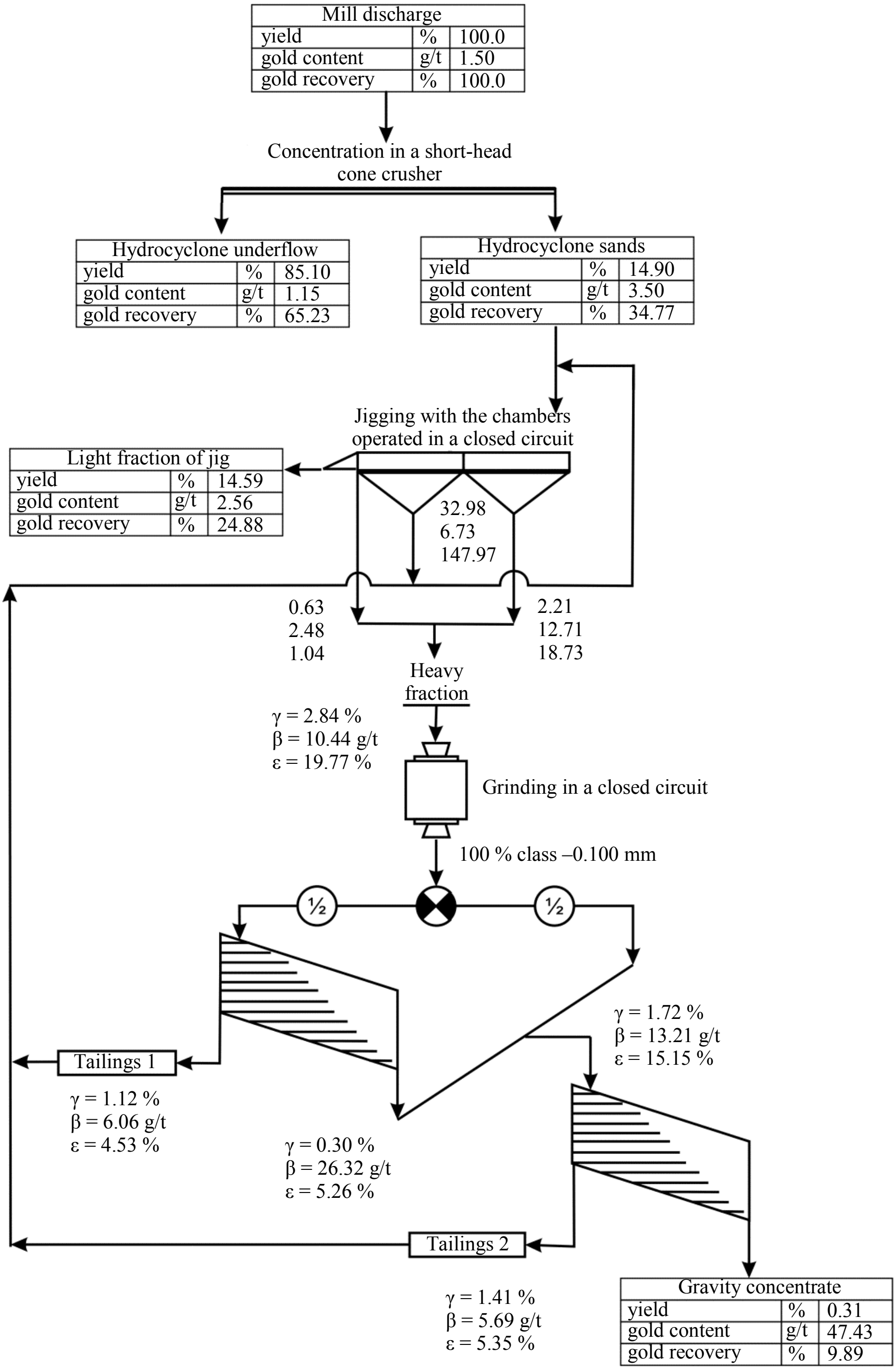

Figure 2. The recommended quality-quantity scheme of associated gold recovery in the *grinding–classification* circuit when concentrating copper-pyrite ore; built based on the experimental results according to the continuous process principle

Рисунок 2. Рекомендуемая качественно-количественная схема попутного извлечения золота в цикле *измельчение–классификация* при обогащении медно-колчеданных руд, составленная по результатам опыта, проведенного по принципу непрерывного процесса the height of the artificial bed in the second chamber of the X_4 machine ranged within h = 23–37 mm under a constant height of the artificial bed in the first chamber of the machine of 74 mm. To create an artificial bed, 5–7 mm steel shot was poured into the removable stencil cells and the stencils were installed in the jig chambers on a screen with 3 x 3 mm cells.

The specific productivity of the jig machine for the feedstock was 14.7 t / (h · m^2) in the experiments.

The Hancock criterion was used as a response function, %,

$$Y = \frac{\varepsilon_{Au} - \gamma_c}{100 - \alpha_{Au}} \cdot 100,$$

where ε_{Au} is the gold recovery into concentrate, %, under the concentrate yield γ_c, %, and the gold content in the base ore α_{Au}, %.

Experiments were duplicated and randomized by arbitrary choice of the experimentation order. Gold content in the concentrates was determined by the assay test. The equality of empirical variances was determined by the Cochran's Q-test. The experimental results were approximated by a linear regression equation:

$$Y = 9.416 + 1.162X_1 + 1.223X_2 + 1.031X_3 + 1.101X_4. \quad (1)$$

The Fisher's criterion test has shown that regression equation (1) adequately describes the experimental data with 95% reliability. The best result of short head cone crusher sand jigging was obtained under cones stroke of 8 mm and their vibration frequency of 250 min^{-1}, the undersize water flow rate of 6.2 m^3/t, and the artificial bed height of 39 mm.

After determining the rational mode of jigging, jig heavy fraction grinding and cleaning on the shaking table were added into the gold recovery scheme. It follows from the results of the experiment carried out under conditions simulating a closed circuit, that with the jig machine, metal recovery grows from 5.12 to 5.97% under the gravity concentrate yield of 0.237% and Au content of 37.77 g/t.

When switching to jigging with closed-circuit chambers, the experimental results were approximated by a linear regression equation, adequate to the experimental data with the 95% reliability of the estimate:

$$Y = 10.291 + 2.032X_1 + 1.586X_2 - 1.367X_3 + 0.737X_4. \quad (2)$$

The adequacy of the plane approximation and the application of the first-order regression equation (2) was confirmed by checking the deviations from the arithmetic-mean of the experiments of the response function values at the central point. By the steepest ascent method, a rational mode of jigging with closed-circuit chambers was found. The selected response function takes on a maximum value under the jig cones stroke of 8 mm and their oscillation frequency of 244 min^{-1}, and 3.95 m^3/t of water application under the jig machine gratings under the artificial bed height of 36 mm. When jig chambers were operated in a closed circuit and rational mode, an experiment was carried out according to the principle of a continuous process.

It was found that when switching to the closed circuit mode, the optimization parameter value grows from 14.45 to 15.98, which corresponds to an increment of gold extraction into the jig concentrate by 1.77% without sacrificing its quality.

Further improvement of gold extraction by the gravity method was associated with shaking tables efficiency growth.

Work optimization of the SKO-0.5 shaking table at the first stage of the research consisted in determining the rational operation mode by the method of mathematical planning of experiments. When cleaning the jig concentrate on the table, the frequency (X_1 = 260–340 min^{-1}) and length (X_2 = 8–16 mm) of the table deck stroke, and water consumption for material flushing (X_3 = 1.1–2.7 m^3/t) were selected as independent variables.

The experimental results were evaluated according to the Hancock criterion. As a result of mathematical processing of the experimental data array, a regression equation has been obtained that connects the selected response function and the parameters of the shaking table operating mode:

$$Y = 2.585 + 0.296X_1 - 0.667X_2 + 0.399X_3. \quad (3)$$

The significance of the coefficients in regression equation (3) was estimated by the Student's criterion. The Fisher’s criterion test showed that regression equation (3) adequately describes the experimental data with a statistical reliability of 95%.

When switching the tables’ operation to the jet scheme, the experimental data were approximated by a regression equation that is adequate to the experimental data with a significance level of 0.05:

$$Y = 5.837 + 1.059X_1 - 1.610X_2 + 0.712X_3. \quad (4)$$

A comparison of regression equations (3) and (4) revealed that regardless of the concentration scheme on the tables, a high frequency and a short stroke length of the deck helps to achieve the maximum value of the response function; flush water consumption in both instances should be high.

The rational modes of jig concentrate cleaning on shaking tables operating according to competing patterns of concentrates motion are determined by the steepest ascent method (Table 1).

It follows from Table 1 that the use of the developed technology of associated gold extraction in the *grinding–classification* circuit is 3.92% higher than with the existing technology; gold content in commercial gravity concentrate is 7.26 g/t higher than at the existing production. When the tables work according to the jet scheme, the frequency of their deck stroke should be 5% higher.

Experiments have been carried out according to a scheme that simulates a closed circuit of associated gold extraction in a *grinding–classification* circuit by gravity concentration methods (Figure 2). In accordance with the diagram in Figure 2, sands of a short head cone crusher are subjected to jigging on a jig machine with chambers operated in a closed circuit; oversize concentrate and heavy fraction of the first chamber are cleaned on shaking tables after grinding. The shaking tables are operated in a mode with feedstock jet motion and rough concentrate.

It follows from the research results that the recommended technology of associated gold recovery in the *grinding–classification* circuit in the course of copper-pyrite ores concentration allows increasing gold recovery by 4.77%, and from 5.12 to 9.89%, namely by 0.85% by concentrating sands in a short head cone crusher on a jig machine; by 1.77% by switching the chambers to a closed circuit; by 2.15% by jet motion of concentrates on the shaking tables.

Conclusion. A technology has been developed for the associated gold extraction in the *grinding–classification* circuit in the course of copper-pyrite ore concentration at the Urupsky field. The developed technology differs from the existing ones (and the ones adopted at the operating concentration plant) by the mode of sand jigging in a short head cone crusher and the scheme of treating heavy jig fraction on shaking tables. The novelty of the jig mode consists in the jig chambers operation in a closed circuit. The novelty of heavy fraction treatment scheme consists in mixing a half of the tables feedstock with rough concentrate separated from the other half of the feedstock. The new jig mode and the scheme with the shaking tables increase gold content in the feedstock, which is the reason for reduced gold loss with the gravity circuit tailings.

In the laboratory conditions, the new jig mode and scheme with the shaking tables have been tested on a sample of ore from the Urupsky field. The research was carried out using the methods of mathematical planning of experiments. The effectiveness of the developed technology has been proven by experiment. Moreover, gold recovery increment by 4.77% was obtained due to the use of all three recommended scientific and technical measures, namely sands concentration in a short head cone crusher on a jig, switching the jig chambers to a closed circuit, and jet motion of concentrates on shaking tables.

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Received 21 June 2021

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УДК 622.7:622.342 DOI: 10.21440/0536-1028-2021-7-35-44

Разработка технологии попутного извлечения золота при обогащении медно-колчеданных руд

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Реферат
Цель работы *– решение актуальной задачи: разработка технологии попутного извлечения золота из комплексных руд.*
Объектом исследования *являлись золотосодержащие медно-колчеданные руды. Извлечение золота из них осуществляли в лабораторных условиях с использованием гравитационных методов разделения минералов.*
Инструменты исследования. *Рациональные режимы работы аппаратов определены с применением математического планирования экспериментов с обработкой полученных результатов математико-статистическими методами.*
Методика проведения исследований. *Извлечение золота осуществляли в цикле измельчение–классификация с использованием последовательно установленных короткоконусного гидроциклона, отсадочной машины и концентрационного стола.*
Результаты. *Разработанный режим отсадки отличается от известных тем, что камеры отсадочной машины работают в замкнутом цикле: из исходного продукта во второй (по ходу движения легкой фракции) камере машины выделяют легкую фракцию (хвосты) и подрешетный продукт – фракцию с повышенным содержанием тяжелых минералов (черновой концентрат). Черновой концентрат, выделенный во второй камере, направляют в первую камеру машины, где получают готовый концентрат отсадки в виде подрешетного продукта. Легкая фракция перемещается из первой камеры во вторую и выводится из машины через сливной порог. При доводке тяжелой фракции отсадки на концентрационном столе рекомендуется смешение 1/2 части исходного питания столов с черновым концентратом, выделенным из другой 1/2 части исходного питания. Новые режим отсадки и схема концентрации на столах обеспечивают увеличение содержания золота в исходном питании аппаратов, что является причиной снижения потерь золота с хвостами цикла гравитации.*

Актуальность. *За счет применения разработанных научно-технических мероприятий: обогащения песков короткоконусного гидроциклона на отсадочной машине, перевода камер отсадочной машины на работу в замкнутом цикле и струйного движения продуктов обогащения при концентрации на столах, получен прирост извлечения золота на 4,77 %.*
Область применения результатов. *Результаты работы рекомендуется использовать при обогащении руд, содержащих свободное (амальгамируемое) золото, а также золотосодержащего пирита.*

Ключевые слова: *медно-колчеданная руда; золото; попутное извлечение; гравитация.*

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Поступила в редакцию 21 июня 2021 года

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Для цитирования: Евдокимов С. И., Герасименко Т. Е. Разработка технологии попутного извлечения золота при обогащении медно-колчеданных руд // Известия вузов. Горный журнал. 2021. № 7. С. 35–44 (In Eng.). DOI: 10.21440/0536-1028-2021-7-35-44

For citation: Evdokimov S. I., Gerasimenko T. E. Developing the technology of associated gold recovery when concentrating copper-pyrite ore. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = News of the Higher Institutions. Mining Journal*. 2021; 7: 35–44. DOI: 10.21440/0536-1028-2021-7-35-44