DOI: 10.31643/2022/6445.28

Increased recovery of free fine gold in the leaching process

Toktar G., Koizhanova A.K.*, Magomedov D.R., Abdyldaev N.N., Bakraeva A.N.

Satbayev University, “Institute of Metallurgy and Ore Beneficiation” JSC, Almaty, Kazakhstan

** Corresponding author email: aigul_koizhan@mail.ru, a.koizhanova@satbayev.university*

Received: *January 17, 2022*
Peer-reviewed: *February 03, 2022*
Accepted: *March 24, 2022*

ABSTRACT

The current state of world mineral resources is characterized by a decrease in the quality of minerals. An increase in production and processing volumes is possible only through the development of new deposits and the involvement of off-balance ores, dumps and tailings, slags and other industrial wastes in the integrated mining process. More increasing the need for involving raw materials of complex composition, refractory, low-grade, with small reserves, technogenic mineral waste. It becomes more and more relevant as the discovery and exploitation of new deposits, allowing to increase the gold reserve of the Republic of Kazakhstan. The article presents the results of sorption leaching of ore in order to extract gold associated with sulfides, the processes of opening gold. A representative sample was taken and the phase composition of an additional explored ore body was studied at one of the deposits in Kazakhstan. The ore sample was prepared for research: three-time mixing by the ring-cone method, in general, three-stage quarting and mixing were performed. It should be noted that the methods for processing gold-bearing ore raw materials depend on many parameters, including the material composition and technological properties. Samples from the last quarting materials were selected for chemical, sieve and phase analyzes. It was found that the test sample contained 6.04 g / t Au and 7.9 g / t Ag, as well as fineness of gold within 0.01-0.25 mm phase analysis. Mineral gold formations can be easily soluble in cyanide solutions (native gold, electrum), partially soluble (maldonite, or practical are insoluble (tellurides). Gold in ores is present in the form of gold-colored sizes and shapes. Both physical (gravity, flotation) and chemical (cyanide, etc.) methods are used to extract it. Rational analysis also found that gold in the ore under study, crushed to a particle size of 90%, class 0.071 mm, gold is free and in intergrowths is 81.46%, gold associated with sulfides is 14.40%, in rock-forming minerals 1.66%. Based on the data obtained, it can be stated that when cyanidating ore, one should expect rather high rates of gold dissolution (80% or more). Gold extraction from ore with a content of 85% fraction -0.071mm-90.2%, with a content of 85% fraction- 0.071mm-98% with oxidative leaching. Full extraction of gold from ore is possible with sorption cyanide leaching with their preliminary oxidation. The paper considers economically feasible existing and promising technologies for gold extraction at the leading factories of Kazakhstan and abroad.

Keywords: gold ore, sorption leaching, chloroactive compound, sorbent, oxidizing agent.

Toktar Gulmira	***Information about authors:*** *phD doctor, research fellow Institute of Metallurgy and Ore Beneficiation JSC, 050013, Almaty, Shevchenko srt., 29/133, Satbayev University, Kazakhstan. ORCID ID: 0000-0003-4110-9013. Email: Gulmiratoktar0@gmail.com*
Koizhanova Aigul Kairgeldyevna	*Candidate of technical sciences, head of the laboratory of special methods of hydrometallurgy. Satbayev University, Institute of Metallurgy and Ore Beneficiation JSC, 050013, Almaty, Shevchenko srt., 29/133, Kazakhstan. ORCID ID: 0000-0001-9358-3193. Email: a.koizhanova@satbayev.university, aigul_koizhan@mail.ru*
Magomedov David Rasimovich	*Master, junior research fellow. Satbayev University, Institute of Metallurgy and Ore Beneficiation JSC, 050013, Almaty, Shevchenko srt., 29/133, Kazakhstan. ORCID ID: 0000-0001-7216-2349. E-mail: d.magomedov@stud.satbayev.university*
Abdyldaev Nurgali Nurlanovich	*Lead engineer, bakalavr of Satbayev University, Institute of Metallurgy and Ore Beneficiation JSC, 050013, Almaty, Shevchenko srt., 29/133, Kazakhstan. ORCID ID:0000-0001-8145-5741; E-mail: nur.ab.kz@mail.ru*
Bakrayeva Akbota Nurdildakyzy	*Engineer, magistr of Satbayev University Institute of Metallurgy and Ore Beneficiation JSC, 050013, Almaty, Shevchenko srt., 29/133, Kazakhstan. ORCID ID: 0000-0002-2062-9573. E-mail: bakraeva.akbota@mail.ru*

Introduction

The current state of world mineral resources is characterized by a decrease in the quality of minerals. An increase in production and processing volumes is possible only through the development of new deposits and the involvement of additionally explored raw materials in the complex, as well as the development of off-balance ores, heaps and tailings, slags and other industrial wastes. The most contemporary important problem of gold hydrometallurgy is the search for rational methods for its extraction from refractory ores and industrial wastes. It becomes more and more relevant as the discovery and exploitation of new deposits, allowing to increase the gold reserve of the Republic of Kazakhstan.

Kazakhstan has significant potential for gold-bearing mineral resources. One of these objects is the ore of one of the deposits of East Kazakhstan. The field was discovered in the 70s of the last century. Exploration of the deeper horizons of the deposit showed the presence of a richer sulfide type of ore.

At present, most gold processing plants process ores in which sulfide minerals are present. Gold in such ores is partially associated with sulfides, and partially is in a free state. In most cases, ores of this type are classified as refractory, and circumstances that exclude the use of enrichment methods are possible.

Technological mineralogy methods allow to identify useful and harmful minerals and their associations in ores, determine the features of their real composition and structure, the nature of relationships between themselves and with rock-forming phases, control, explain and predict the behavior of ores in technological processes. Cyanide leaching is the main method for extracting gold from ores both in traditional technology and in geotechnological mining. Sodium cyanide or potassium cyanide salts with a concentration of 0.02-0.3% are used as a reagent.

The dissolution of gold in cyanide solutions occurs in the presence of oxygen by the reaction:

$$2Au+4NaCN+SO_2+H_2O = 2Na[Au(CN)_2] + 2NaOH \quad (1)$$

From the reaction it is clear that gold passes into the solution in the form of a gold-cyanide salt of sodium, which dissociates in solution into ions:

$$Na[Au(CN)_2] = Na^{+}+[Au(CN)_2]^{-} \quad (2)$$

The possibility of the occurrence of an electrochemical dissolution of gold is determined by the electromotive force equal to the potential difference of the anodic and cathodic processes. In addition, in the presence of a complexing agent, in particular, a CN ion, the activity of Au ions in solution decreases during the formation of a very strong $[Au(CN)_2]^{-}$ complex.

The instability constant of this complex is characterized by a very small value:

$$K = \frac{[Au]\times[CN]^2}{[Au(CN)_2]^-} = 5 \times 10^{-38} \quad (3)$$

Therefore, in the presence of CN ions, the activity of Au ions decreases sharply, which means that the potential of gold decreases and its oxidation becomes thermodynamically possible [[1], [2], [3], [4]]. The potential for dissolving gold with the formation of a cyanide complex is -0.611 V, while the potential of gold itself is equal to + 1.8 V.

At the same time, studies noted that an increase in the oxygen concentration in the solution increases the passivation of the gold surface and, as a result, there is a strong anodic inhibition of the dissolution process. An excess of alkali in a solution (pH-12) of hydrogen peroxide leads to the same effect, which contribute to the formation of thick oxide films on the metal surface. However, it should be noted that the addition of chloroactive compounds increases the rate of dissolution of the noble metal. This is in favor of the adsorption mechanism of passivation of gold by oxygen. A.N. Frumkin noted that when oxygen is adsorbed, along with a change in the double layer, the chemical nature of the metal surface changes, which should affect the rate of the dissolution process [[5], [6], [7]]. The addition of a chloroactive compound to the solution leads to the adsorption displacement of oxygen from the gold surface, its partial depassivation, and an increase in the dissolution rate. All of the above applies directly to free metallic gold. At the same time, the main problem for the gold mining industry is persistent sulfide ores and concentrates, in which gold is closely associated with pyrite and arsenopyrite. These minerals are chemically stable and are not amenable to direct leaching with solutions of acids and alkalis. For such raw materials, various methods of opening, grinding, bioleaching, roasting, oxidation of autoclaves, etc., were proposed before the cyanide process. The study of the decomposition of arsenopyrite and pyrite. showed that their chemical resistance is largely dependent on the nature of the solvent used. The most favorable conditions for the oxidation of these minerals are created in alkaline solutions in the presence of an oxidizing agent.

The aim of the work was to conduct research and development of a sorption technology for the extraction of gold from further explored ores [[8], [9], [10], [11], [12], [13]].

Methods of analysis

X-ray phase analysis was carried out on a D8 Advance diffractometer (BRUKER), α-Cu radiation. Diffraction pattern shooting conditions: U = 35 kV; I = 20 mA; scale: 2000 imp; time constant 2s; shooting theta-2ta; detector 2 deg / min

Currently, most GEFs process ores in which sulfide minerals are present. Gold in such ores is partially associated with sulfides, and partially is in a free state. In most cases, ores of this type belong to the category of resistant. The raw material for gold extraction is gravity-flotation concentrate from ore enrichment. The methods of technological mineralogy make it possible to identify useful and harmful minerals and their associations in ores, to determine the features of their real composition and structure, the nature of relationships between themselves and with rock-forming phases, to control, explain and predict the behavior of ores in technological processes [[14], [15], [16], [17], [18]].

The raw material base of the gold mining industry of Kazakhstan is mainly represented by small (with reserves up to 25 tons) and medium (from 25 to 100 tons) deposits. However, the leading position is occupied by the deposits of Eastern, Northern and Central Kazakhstan. The search for the most effective integrated technology for extracting gold from mineral raw materials is an urgent task of the gold mining industry of Kazakhstan.

One of the key processes in the technology of processing of resistant fine-grained ores is the process of their opening, which provides access of the leaching reagent to the surface of micro- and nanoparticles of gold. The conducted studies of hydrometallurgical methods for extracting gold from low-sulfide ores allowed us to make a choice and justify the prospects for the use of pre-oxidation [[19], [20], 21]].

Experimental part

The object of research was the ore of the processing plant of the deposits of East Kazakhstan. In preparation for research, the sample was crushed in stages to a particle size of -2.5 + 0 mm, was quarting, mixed, and reduced in accordance with the standard sampling methodology (samples) for technological studies and the study of material composition. Ore crushing was carried out on laboratory jaw and roll crushers and grinding on ball, rod and bead mills and vibro-crusher. The ore sample is a finely ground material with a particle size of 100 % class – 0.071 mm. The chemical composition of the studied tailings sample is represented by the following main components, %: 4.27 Fe; 9.02 Fe_2O_3; 8.1 FeO; 0.010 As; 0.072 Zn; 0.016 Cu; 6.04 g / t Au; 7.9 g / t Ag.

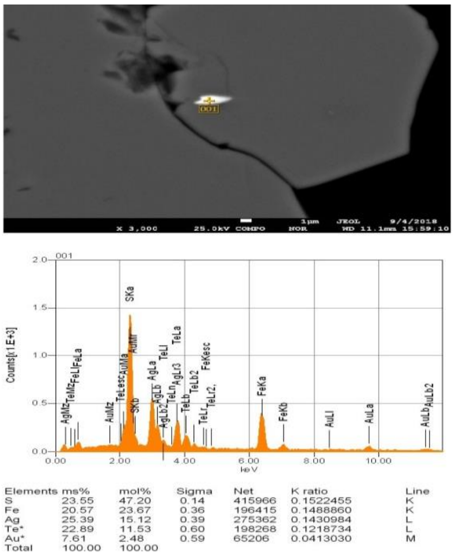
Ore cyanidation products — solution and cake — were subjected to atomic adsorption and assay assays, respectively.

Electron microscopic studies of the basic sulfide mineral arsenopyrite extracted from the initial tailings sample were carried out using a JEOL JXA-8230 scanning electron microscope (Japan) equipped with an energy dispersive analyzer. As can be seen in fig. 1, pyrite in addition to the basic structural elements - iron and sulfur also contains gold and trace elements of copper and zinc.

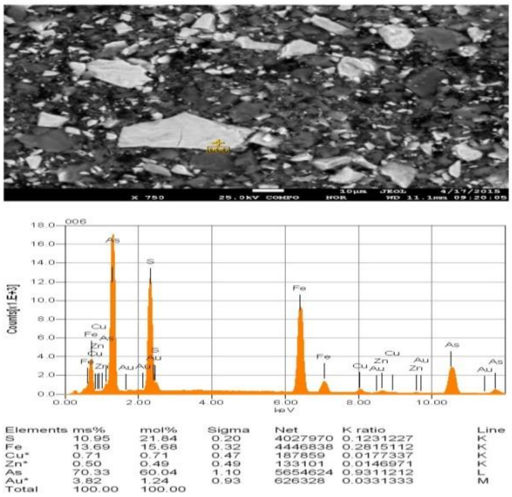
From the results of a rational (phase) analysis of the gold in the ore, finely ground to a fineness of 90 % of the class –0.071 mm (table 1), it follows that the content of free gold in the intergrowths (cyanide gold) is 81.46 %. The presence of finely disseminated gold in sulfides is one of the main reasons for the technological persistence of mineral raw materials. 14.4 0% of gold is associated with sulfides, 2.48 % is associated with acid-soluble compounds. In the rock-forming minerals, the gold content (0.10 g / t, or 1.66 %).

Table 1 - The results of a phase (rational) analysis for gold of a crushed sample of the original ore with a particle size of 90 % of the class -0.071 mm

Forms of gold in ore	Gold allocation	
	g/t	%
Free form	4.92	81.46
Associated with acid-soluble minerals (carbonates, hydroxides, chlorites, etc.)	0.15	2.48
Associated with Sulfides	0.87	14.40
Finely interspersed in rock-forming minerals	0.10	1.66
Total in sample (balance sheet)	6.04	100.0



a)



b)

Figure 1 - energy dispersive analysis of the microstructures of gold (a) in pyrite and (b) in a fragment of arsenopyrite

The data of X-ray phase analysis of the sample showed that the bulk of the sample is represented by silicon oxide (54.7%). The proportion of pyrite in the sample (3.4%). Clinochlor is a mineral belonging to phyllosilicate ammonium and aluminum with hydroxyl, the proportion of which is 11.2% (figure 2).

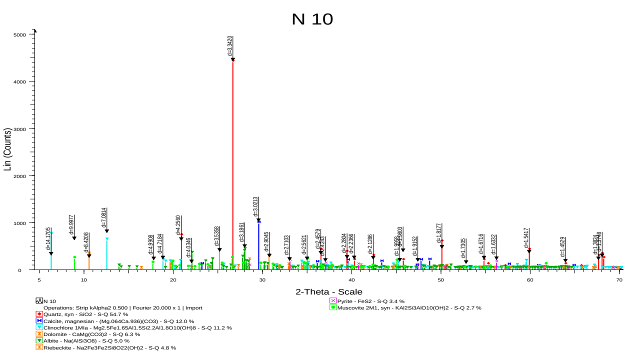


Figure 2 - Diffractogram of an ore sample

To find the forms of gold, a rational analysis of the ore sample was performed with the initial size class -0.05 mm and +0.05 mm. Under an optical microscope Axio Scope.A1, a polished section (∅ = 25 mm, m $_{weights}$ = 12-17 grams) formed from this material was studied. As a result, found 33 golden particles, of which:

- 26 particles in free form - 78.8%, Au dimension from 0.5 to 6.9 mkm, i.e. ultrafine, finely dispersed gold (Figure 3, 4);
- 7 particles in intergrowths with waste rock - 21.2%, with parameters - Au from 0.4 to 8.4 mkm (Figure 3). The particle size is in the range: Au (0.4-8.4 mkm), i.e. ultrafine (0.1-1.0 mkm) and finely dispersed gold (1.0-10.0 mkm) (according to Petrovskaya's classification "Native gold").

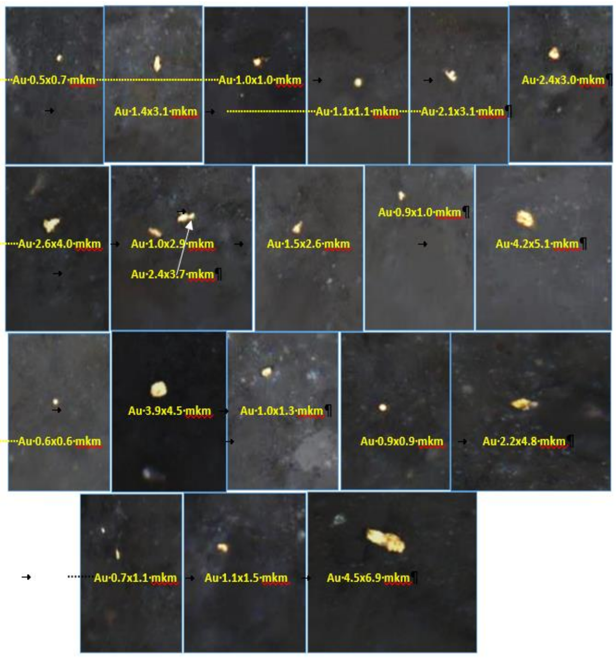


Figure 3 - Free gold in binder polystyrene

Below, in Figure 4, gold particles in the free state are noted, covered with oxidation films, possibly of goethite-limonite composition, which, in turn, gives them a reddish tint.

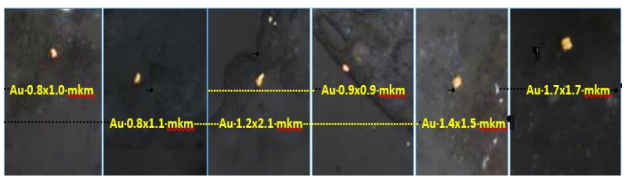


Figure 4 - Free gold particles covered with oxidation films

Table 2 - the results of the leaching of gold from the source ore

Nomination	Parameters		
	85% - 0,071mm	85% - 0,071 mm	85% - 0,071mm
Sample weight, g	300	300	300
The mass of the solution, g	900	900	900
CaO, kg/t 70% activity	1.5	1,5	1.5
The density of the pulp during cyanidation,% solid	30	30	30
The concentration of NaCN,%	0.1	0.1	0.1
pH	11.3	11.4	11.2
Type of sorbent / oxidizing agent, g	-	Gold Carb 207C	$Ca(ClO)_2$ +*Cl^{n+} 2.5
Au content in initial sample by assay, g/t	6.04	6.04	6.04
Au content in the tailings solid residue (cake), g / t	0.59	0.5	0.12
The degree of dissolution of Au,%	90.2	91.6	98.0

Under conditions of ore treatment with preliminary oxidation by a chloroactive complex of compounds (≈ 30% Ca $(ClO)_2$ + 70% * Cl^{n+}), subsequent washing of the cake with water and cyanide leaching (pH = 11.2 solid: liquid = 1: 3, and 1 g / dm3 NaCN, the duration of 24 hours of gold recovery is 98.0%. With direct cyanidation, the recovery rate was only 90.2%. Sorption recovery reached 91.6%.

Discussion of the results

The results presented in table 2 indicate that during direct, sorption and pre-oxidation leaching, the gold content in the leaching tailings decreases to 0.59-0.12 g/t and the degree of gold dissolution increases to 90.2-98.0%. During sorption cyanidation, the consumption of sodium cyanide and alkali (calcium oxide) increased slightly (Table 2). This is due to the fact that GoldCarb 207C activated carbon has the ability to sorb cyanide compounds and hydroxide ions. The increase in the consumption of sodium cyanide during the transition from direct cyanidation to sorption is associated with the sorption of CN-activated carbon ions.

Based on the results of the conducted research, the following modes for hydrometallurgical processing of ore from the Sekisovsky deposit are recommended:

- grinding fineness 55% -0.071 mm;
- the concentration of sodium cyanide in the liquid phase of the pulp is 0.1%, pH 10.5-11.0;
- the ratio of solid to liquid in the pulp S:L = 1:3 (the solid content in the pulp is 33.3%);
- cyanidation time is 24 hours;
- cyanidation of gold from ore is carried out in the presence of a sorbent (sorption leaching).

Carrying out the process in this mode allows 91.6% of gold to be dissolved from the ore with its almost complete extraction by the sorbent and to obtain tails of sorption cyanidation with a minimum gold content of 0.5 g/t.

When comparing test 1 and test 3 on a crushed product, it follows: after preliminary oxidative treatment of the material, the extraction is higher by 7.8% (98.0% compared to the test without oxidative treatment - 90.2%).

It follows from the above: in order to increase the extraction of gold from the ore of the Sekisovsky deposit by cyanidation, preliminary oxidative treatment has a positive effect.

Conclusion

It was revealed that the sulfide ore under study according to assay data contains 6.0 g / t gold, 7.9 g /t silver and belongs to the sulphide gold-quartz type. The ore is characterized by a multicomponent mineral composition with a predominance of iron-containing pyrite and is practically not affected by oxidation processes. The study of mineralogical and x-ray phase analysis and samples showed that the bulk of the ore is represented by pyrite with rare fragments of gold-bearing arsenopyrite. The only valuable component in the sample of industrial interest is gold, and silver recovery can be considered as an associated metal. Rational analysis found that in the ore under study gold is free and in intergrowths is 85.51%, gold associated with sulfides is 11.81%, in membranes 1.46%, in gangue 1.22%. However, the formation of various types of membranes covering the surface of free gold can to some extent slow down the cyanidation process. Thus, the use of preliminary oxidation by chloroactive compounds promotes a more complete recovery of noble metals by eliminating impurities of various types of membranes forming on the surface of free gold. In addition, the oxidizing properties of chlorine can reveal sulfide gold-bearing minerals, such as pyrite and arsenopyrite, which also contributes to a more complete extraction. Thus, the use of a complex of chloroactive compounds made it possible to extract an additional 7.8% of gold from the sample under study compared with direct cyanidation, which ultimately amounted to 98% of gold transferred to a productive solution.

Conflict of interests. On behalf of all authors, the correspondent author declares that there is no conflict of interest.

Acknowledgement

The Ministry of Education and Science of the Republic of Kazakhstan financially supported this work under the grant funding AP08051925.

Cite this article as: Toktar G, Koizhanova AK, Magomedov DR, Abdyldaev NN, Bakraeva AN. Increased recovery of free fine gold in the leaching process. Kompleksnoe Ispol'zovanie Mineral'nogo Syr'a = Complex Use of Mineral Resources 2022;322(3):51-58. https://doi.org/10.31643/2022/6445.28

Шаймалау процесінде бос алтын алуды арттыру

Токтар Г., Койжанова А.К., Магомедов Д.Р., Абдылдаев Н.Н., Бакраева А.Н.

Сәтбаев университеті, «Металлургия және кен байыту институты» АҚ, , Алматы, Қазақстан

Мақала келді: *17 қаңтар 2022*
Сараптамадан өтті: *03 ақпан 2022*
Қабылданды: *24 наурыз 2022*

ТҮЙІНДЕМЕ

Әлемдік минералдық-шикізат ресурстарының қазіргі жай-күйі пайдалы қазбалар сапасының төмендеуімен сипатталады. Өндіру мен қайта өңдеу көлемін ұлғайту жаңа кен орындарын игеру және баланстан тыс кендерді, үйінділер мен қалдықтарды, шлактар мен өнеркәсіптің басқа да қалдықтарын кешенді игеруге тарту есебінен ғана мүмкін болады. Құрамы күрделі, төзімді, төмен сұрыпты, аз қоры бар, техногендік шикізатты өңдеуге тарту қажеттілігі барған сайын артып келеді. Ол Қазақстан Республикасының алтын қорын ұлғайтуға мүмкіндік беретін жаңа кен орындарының ашылуына және пайдаланылуына қарай барынша өзекті бола түсуде. Мақалада сульфидтермен астасқан алтынды алу мақсатында кенді сорбциялық сілтісіздендіру нәтижелері, Алтынды ашу процестері келтірілген. Өкілдік сынаманы іріктеу жүзеге асырылды және Қазақстанның кен орындарының бірінің жете зерттелген кен денесінің фазалық құрамы зерделенді. Кен сынамасын зерттеуге дайындау орындалды: "сақина-конус" әдісімен үш рет араластыру, жалпы үш сатылы кварталау және араластыру орындалды. Құрамында алтын бар кен шикізатын өңдеу әдістері материалдық құрамы мен технологиялық қасиеттерін қамтитын көптеген параметрлерге байланысты екенін атап өткен жөн. Химиялық, елек және фазалық талдауларға соңғы тоқсандағы материалдардан сынамалар алынды. Зерттелетін сынамада 6,04 г/т Au және 7,9 г/т Ag, сондай-ақ фазалық талдау арқылы 0,01-0,25 мм шегінде золотиннің ірілігі бар екені анықталды. Алтынның минералды түзілімдері цианид ерітінділерінде оңай ериді (табиғи алтын, электрум), ішінара ериді (мальдонит немесе іс жүзінде ерімейді (теллуридтер). Рудадағы алтын алтын мөлшері мен формасы түрінде болады. Оны алу үшін физикалық (гравитация, флотация) және химиялық (цианизация және т.б.) әдістер қолданылады. Рационалды талдау сонымен қатар зерттелетін кендегі алтынның 0,071 мм класының 90% - ына дейін ұсақталғаны, алтын бос және көштерде 81,46%, сульфидтермен байланысқан алтын 14,40%, тау жыныстарын құрайтын минералдарда 1,66% екендігі анықталды. Алынған деректер негізінде кенді циандау кезінде Алтынды еріту бойынша жеткілікті жоғары көрсеткіштерді (80% және одан жоғары) күту керек деп айтуға болады. Құрамында 85% фракция -0,071 мм-90,2% болса, 85% фракция-0,071 мм-98% болса, алдын ала тотығу кезінде кеннен алтын алу. Алтынды кеннен толық алу оларды алдын ала тотықтыра отырып, сорбциялық цианидті шаймалау кезінде мүмкін болады. Жұмыста Қазақстанның алдыңғы қатарлы фабрикаларында және шетелдерде алтын алудың экономикалық тұрғыдан орынды қолданыстағы және перспективалы технологиялары қарастырылды.

Түйін сөздер: (құрамында алтын бар кен, сорбциялық сілтісіздендіру, хлорактивті қосылыс, сорбент, тотықтырғыш.

Авторлар туралы ақпарат:

Токтар Гулмира — *phD ғылым докторы, ғылыми қызметкер, Satbayev University, Металлургия және кен байыту институты, 050013, Қазақстан, Алматы, Шевченко к-сі, 29/133. ORCID ID:0000-0003-4110-9013. Email: Gulmiratoktar0@gmail.com*

Койжанова Айгуль Кайргельдыевна — *Техника ғылымдарының кандидаты, гидрометаллургияның арнайы әдістері зертханасының меңгерушісі. Satbayev University, Металлургия және кен байыту институты, 050013, Қазақстан, Алматы, Шевченко к-сі, 29/133. ORCID ID: 0000-0001-9358-3193. Email: aigul_koizhan@mail.ru, a.koizhanova@satbayev.university*

Магомедов Давид Расимович — *Кіші ғылыми қызметкер, магистр, Satbayev University, «Металлургия және кен байыту институты» АҚ, Қазақстан, 050013, Алматы қ., Шевченко к-сі, 29/133. ORCID ID: 0000-0001-7216- 2349. E-mail: davidmag16@mail.ru*

Абдылдаев Нургали Нурланович	*Жетекші инженер, бакалавр, Satbayev University, «Металлургия және кен байыту институты» АҚ, Қазақстан, 050013, Алматы қ., Шевченко к-сі, 29/133. ORCID ID: 0000-0001-8145-5741; E-mail: nur.ab.kz@mail.ru*
Бакраева Ақбота Нұрділдақызы	*Инженер, магистр, Satbayev University, «Металлургия және кен байыту институты» АҚ, Қазақстан, 050013, Алматы қ., Шевченко к-сі, 29/133. ORCID ID: 0000-0002-2062-9573; E-mail: bakraeva.akbota@mail.ru*

Повышение извлечения свободного золота в процессе выщелачивания

Токтар Г., Койжанова А.К., Магомедов Д.Р., Абдылдаев Н.Н., Бакраева А.Н.

Satbayev University, АО «Институт металлургии и обогащения», Алматы, Казахстан

Поступила: *17 января 2022*
Рецензирование: *03 февраля 2022*
Принята в печать: *24 марта 2022*

АННОТАЦИЯ

Современное состояние мировых минерально-сырьевых ресурсов характеризуется снижением качества полезных ископаемых. Увеличение объемов добычи и переработки возможно лишь за счет освоения новых месторождений и вовлечения в комплексную отработку забалансовых руд, отвалов и хвостов, шлаков и других отходов промышленности. Все более возрастает необходимость вовлечения в переработку сырья сложного по составу, упорного, низкосортного, с небольшими запасами, техногенного. Она становится все более актуальной по мере открытия и эксплуатации новых месторождений, позволяющих увеличить золотой запас Республики Казахстан. В статье приведены результаты сорбционного выщелачивания руды с целью извлечения золота, ассоциированного с сульфидами, процессы вскрытия золота. Осуществлен отбор представительной пробы и изучен фазовый состав доразведанного рудного тела одно из месторождений Казахстана. Выполнена подготовка пробы руды к исследованиям: трехкратное перемешивание методом «кольцо-конус», в целом выполнено трехступенчатое квартование и перемешивание. Следует отметить, что методы переработки золотосодержащего рудного сырья зависят от многих параметров, включающих в себя вещественный состав и технологические свойства. На химический, ситовой и фазовый анализы отобраны пробы из материалов последнего квартования. Установлено, что в исследуемой пробе содержится 6,04 г/т Au и 7,9 г/т Ag, а также крупность золотин в пределах 0,01-0,25мм фазовым анализом. Минеральные образования золота могут быть легко растворимы в цианидных растворах (самородное золото, электрум), частично растворимы (мальдонит, или практически нерастворимы (теллуриды). Золото в рудах присутствует в виде золотинразных размеров и форм. Для его извлечения применяют как физические (гравитация, флотация), так и химические (цианирование и т.п.) методы. Рациональным анализом установлено также, что золото в исследуемой руде, измельченной до крупности 90 % класса 0,071 мм, золото свободное и в сростках составляет 81,46 %, золото ассоциированого с сульфидами 14,40 %, в породообразующих минералах 1,66 %. На основании полученных данных можно констатировать, что при цианировании руды следует ожидать достаточно высоких показателей по растворению золота (80 % и более). Извлечение золота из руды при содержании 85% фракции -0,071мм-90,2%, при содержании 85% фракции-0,071мм-98% при предварительном окислении. Полное извлечение золота из руды возможно при сорбционном цианидном выщелачивании с предварительным их окислением. В работе рассмотрены экономически целесообразные действующие и перспективные технологии извлечения золота на передовых фабриках Казахстана и за рубежом.

Ключевые слова: золотосодержащая руда, сорбционное выщелачивание, хлорактивное соединение, сорбент, окислитель.

Информация об авторах:

Токтар Гулмира	*phD доктор наук, научный сотрудник, Satbayev University, АО «Институт металлургии и обогащения», 050013, г. Алматы, ул. Шевченко, 29/133, Казахстан. ORCID ID:0000-0003-4110-9013. E-mail: Gulmiratoktar0@gmail.com*
Койжанова Айгуль Кайргельдыевна	*Кандидат технических наук, заведующая лабораторией спецметодов гидрометаллургии. Satbayev University, Институт Металлургии и Обогащения, 050013, ул. Шевченко, 29/133, Алматы, Казахстан. ORCID ID: 0000-0001-9358-3193. Email: aigul_koizhan@mail.ru, a.koizhanova@satbayev.university*
Магомедов Давид Расимович	*Младший научный сорудник, магистр, Satbayev University, АО «Институт металлургии и обогащения», 050013, г. Алматы, ул. Шевченко, 29/133, Казахстан. Идентификатор ORCID ID: 0000-0001-7216-2349. E-mail: davidmag16@mail.ru*
Абдылдаев Нургали Нурланович	*Ведущий инженер, бакалавр, Satbayev University, АО «Институт металлургии и обогащения», 050013, г. Алматы, ул. Шевченко, 29/133, Казахстан. ORCID ID: 0000-0001-8145-5741; E-mail: nur.ab.kz@mail.ru*
Бакраева Ақбота Нұрділдақызы	*Инженер, магистр, Satbayev University, АО «Институт металлургии и обогащения», 050013, г. Алматы, ул. Шевченко, 29/133, Казахстан. ORCID ID: 0000-0002-2062-9573; E-mail: bakraeva.akbota@mail.ru*

References

[1] Plaksin IN. Metallurgy of precious metals. M.: Metallurgizdat. 1958;367.

[2] Koizhanova A, Mukusheva A, Osipovskaya L, Erdenova M. Estudio de la Cinética de Sorción en Procesos de Recuperación de Metales Preciosos. [Study of Sorption Kinetics in Processes of Precious Metals Recovery]. XXVI Congreso Internacional de Procesamiento de Minerales [XXVI International mineral Prosessing Congress.] New Delhi, India, 2012; 590-601. ISBN: 81-901714-3-7.

[3] Chanturia VA. Osnovnyye napravleniya kompleksnoy pererabotki mineral'nogo syr'ya [The main directions of complex processing of mineral raw materials]. Mining magazine. 1995;1:50-54 (in Rus.)

[4] Koizhanova AK, Toktar G, Craig E, Banks, Magomedov DR, Kubaizhanov AA. Research of hydrometallurgical method of leaching gold from flotation tails with using bio-oxidation. Kompleksnoe Ispol'zovanie Mineral'nogo Syr'a = Complex Use of Mineral Resources. 2020;3(314):28-39. https://doi.org/10.31643/2020/6445.24

[5] Begalinov A, Yakovlev AP. i dr. Tiosul'fatnoye vyshchelachivaniye zolota [Thiosulphate leaching of gold]. Teoriya I praktika. Almaty. 2001;254 (in Rus.)

[6] Kotlyar YuA, Meretukov MA, Strizhko LS. Metallurgiya blagorodnykh metallov [Metalurgia de los metales nobles]. Textbook. 2005(2):432 (in Rus.)

[7] Lodeyshchikov VV. Tekhnologiya izvlecheniya zolota I serebra iz upornykh rud [Technology for extracting gold and silver from refractory ores]: V 2 t. – Irkutsk: Izd-voIrgiredmet. 1999;2: 452 (in Rus.).

[8] Sedel'nikova GV, Kim DKH, Ibragimova N V. Sravneniye sovremennoy tekhnologii kuchnogo bakterial'nogo vyshchelachivaniya s traditsionnoy flotatsionno-tsianistoy pererabotkoy upornoy zolotosul'fidnoy medno-tsinkovoyrudy [Comparison of modern technology of heap bacterial leaching with traditional flotation-cyanide processing of refractory gold-sulfide copper-zinc ore] Rudy imetally. 2015;3:59-69 (in Rus.)

[9] Yerdenova MB, Koyzhanova AK, Kamalov EM, Abdyldayev NN, Abubakriyev AT. Doizvlecheniye zolota iz otkhodov pererabotki zolotosoderzhashchikh rud [Re-extraction of gold from waste processing of gold-bearing ores]. Kompleksnoye ispol'zovaniye mineral'nogo syr'ya. 2018;2:12-20. https://doi.org/10.31643/2018/6445.2

[10] Meretukov MA, Turin KK. Povedeniye zolota v khvostovykh otvalakh // Tsvetnyye metally. 2011;7:27-31. (in Russ)

[11] Kenzhaliev BK, Koizhanova AK, Sedelnikova GV, SurkovaTYu, Kamalov EM, Erdenova MB, Magomedov DR. Extraction of gold from flotation tails of gold-processing plant. Izvestiya NAN RK. 2017;6:62-69. ISSN 2224-5286

[12] Filippova YeV. Analiz mekhanizmov migratsionnoy aktivnosti zolota i soputstvuyushchikh elementov pri razrabotke geotekhnologii // Vestnik Zabaykal'skiy. 2016;(22)11:42-51. DOI: 10.21209/2227-9245-2016-22-11-42-51

[13] Sanchez R. Strategic flexibility in product competition. Strategic Menagement journal. 1995;16(S1):135-159. https://doi.org/10.1002/smj.4250160921

[14] Koizhanova AK. et al. Research on the technology for recovering gold from spent heap leaching ore piles. Obogashchenie Rud. 2019;3:54-59. Available at: https://doi.org/10.17580/or.2019.03.09.

[15] Kaumetova DS, Koizhanova AK, Absalyamov KhK, Magomedov DR, Banks CE. Studies of the rate of gold sorption by the AM-2B anionite from cyanide-alkaline solutions. Kompleksnoe Ispol'zovanie Mineral'nogo Syr'a = Complex Use of Mineral Resources. 2022;320(1):88-94. https://doi.org/10.31643/2022/6445.10

[16] Koizhanova AK, Sedel'nikova GV, Kamalov Je M, Erdenova MB, Abdyldaev NN. Izvlechenie zolota iz lezhalykh khvostov zolotoizvlekatel'noj fabriki = Extraction of gold from the stale tails of the gold recovery factory.Otechestvennaya geologiya. 2017;6:98-102. (in Rus.)

[17] Kenzhaliyev OB, Ilmaliyev ZhB, Tsekhovoy AF, Triyono MB, Kassymova GK, Alibekova GZh, Tayauova GZh. Conditions to facilitate commercialization of R & D in case of Kazakhstan. Technology in Society. 2021;67:101792. https://doi.org/10.1016/j.techsoc.2021.101792

[18] Kotlyar Yu A, Meretukov MA, Strizhko LS. Metallurgy of precious metals: Textbook in 2 books-M.: MISIS, Ed. house "Ore and metals". 2005;2:392 .

[19] Kenzhaliyev BK, Surkova TY, Abdikerim BE, Berkinbayeva A N, Abikak YB, Yessimova DM. Research on sorption properties of phosphoric production slag-waste Metalurgijathis link is disabled. 2022; 61(1): 209-212.

[20] Kenzhaliyev BK, Surkova, TY, Azlan MN, Yulusov SB, Sukurov, BM, Yessimova DM. Black shale ore of Big Karatau is a raw material source of rare and rare earth elements Hydrometallurgy. 2021;205:105733. https://doi.org/10.1016/j.hydromet.2021.105733

[21] Koizhanova A.K., Berkinbayeva A.N., SedelnikovaG.V., B.K. Kenzhaliyev, MagomedovD.R., Efremova (Dyo) Y.M. Research of biochemical gold recovery method using high-arsenic raw materials. Metalurgua. 2021; 60 (3-4): 423-426.