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EXTRACTION OF GOLD FROM FLOTATION TAILS OF GOLD-PROCESSING PLANT

Abstract. A representative sample of dump flotation tailings is selected and its chemical, phase and mineralogical composition is studied. It is shown that gold is in association with quartz, and is present mainly in a finely dispersed form in the intergrowths, which requires a careful choice of conditions and the way it is extracted. In the course of the studies, a direct cyanidation of the tailings was carried out, as well as with the preliminary action of the oxidants. Oxidation with chemical reagents - sodium peroxide and calcium hypochlorite and various strains of biocultures was used. Studies have shown that preliminary re-grinding and oxidation of tailings makes it possible to increase the degree of leaching of gold at the subsequent cyanidation stage by 2.34% compared to direct cyanidation.

The most effective oxidizer is calcium hypochlorite, then the biocultures and sodium peroxide follow the oxidation state, the bioculture strain isolated from the one with the flotation tailings of the deposit is the most active oxidizer, so that the microorganisms adapt quickly to the material composition of the object under study and the biooxidation process takes place much more intensively, than when using bacterial cultures isolated from other deposits.

The results of the cake study after biooxidation by the method of electron-raster microanalysis (SEM) showed a visible change in its structure relative to the initial feedstock: after biooxidation, the gaps and openings formed are clearly visible on the topographic image. The result of such a change in structure is the destruction of the bonds of gold with rock-forming minerals and, as a consequence, an increase in the degree of leaching of gold during cyanidation.

The conducted researches established that the use of oxidizing agents as intensifiers allows to increase the degree of gold recovery from man-made waste, bio-oxidation should be considered the most environmentally safe.

Key words: gold, flotation tails, biooxidation, cyanidation, hydrometallurgy.

Introduction

In connection with the depletion of gold ore reserves, low-grade, off-balance raw materials are increasingly involved in production, and as a result, the amount of man-made waste is growing. Tailings of flotation are one type of such waste. As a rule, it is a stubborn, difficult-to-hide raw material that did not lend itself to opening during the processing of the original ore. However, the content of precious metals in such raw materials is often higher than in low-grade mineral.

The development and development of technology for extracting gold from accumulated technogenic and mineral objects, first of all from dumps, tailings of gold recovery factories and industries, acquires special significance for many gold mining enterprises, where the raw stock of conditioned ore is close to depletion. In this connection, researchers pay great attention to the development of new methods that can be competitive and effective in extracting precious metals from low-grade and technogenic raw materials.

The youngest and most promising direction is biotechnology, which mainly provides for biooxidation. Bio-oxidation of gold and related metals from technogenic raw materials is considered as the most acceptable, less expensive and environmentally safe method [1-20].

The experimental part

In the process of research, the tailings of the flotation of the gold recovery plant (ZIF) Altynau Kokshetau were used as a raw material, their chemical, mineralogical and phase composition was studied.

According to the chemical analysis the composition of the feedstock is the following,%: Fe - 1.578; S is 0.2; Cu - 0.002; Pb 0.0001; Zn = 0.001; Bi-0.0006; As is 0.108; MgO: 1.100; Al2O3 - 14.60; SiO2 = 66.98; CaO = 3.765; So4-2 - 0.0196; Au - 0.43 g / t.

The phase composition of flotation tailings tailings presented in Table 1.

Table 1 - Phase composition of flotation tailings tailings

Name	Formula	S-Q, %
Albite	$Na(AlSi_3O_8)$	29,4
Microcline	$(K_{95}Na_{05})AlSi_3O_8$	27,8
Quartz, syn	SiO_2	19,5
Magnesiohornblende	$Ca_2Mg_4(AlFe\text{-}3)Si_7AlO_{22}(OH)_2$	11,2
Calcium Iron Aluminium Oxide	$Ca_4Fe_{1.5}Al_{17\cdot67}O_{32}$	9,1
Clinochlore	$Mg_{4\cdot88}Fe_{0.22}Al_{1\cdot881}Si_{2\cdot96}O_{10}(OH)_8$	1,7
Cristobalite	SiO_2	1,3
Total:		100,0

It can be seen from the table that, in general, the phase composition is represented by minerals of silicon, iron and aluminum, calcium and magnesium are less present.

The results of the mineralogical analysis confirm these conclusions and point to the minerals with which gold is associated.

According to mineralogical research, the associated ore components are:

- sulphides: arsenopyrite (FeAsS) - 46%, chalcopyrite (CuFeS2) -10%, pyrite (FeS2) - 9%, marcasite (FeS2) and bismuthine (Bi2S3) are very rare.

- iron oxides and hydroxides: magnetite (FeFe2O4) - 35%, in small amounts there are hematite (αFe2O3), goethite / hydrogoethite (HFeO2 / HFeO2 • ag).

Of the rock-forming minerals, quartz, feldspar, and less often mica are noted.

It can be seen from the above results that in the flotation tailings tailings, gold is in association with quartz, and is present mainly in a finely dispersed form in the intergrowths, which requires a careful choice of conditions and the way it is extracted.

In the course of the studies, the flotation tailings were further ground on a ball mill with a yield of 92% of the -0.044 mm class and their direct cyanidation was carried out. In fine material, gold is more fully disclosed, which provides maximum access to cyanide solution during agitation.

Direct cyanidation conditions (variant 1): sample mass 100 g (90% -0.044 mm), alkaline cyanide solution with concentration 0.2%, time 24 h, T: F = 1: 3 with air supply. During the cyanidation Au- 0.1 mg / l passed into the solution; Cu- 2.2 mg / l; Fe 6.1 mg / l.

At the next stage of the study, the influence of preliminary influence of chemical and biological oxidants on the cyanidation process of pre-ground tails of flotation was studied (experiments 1 and 2). Sodium peroxide and calcium hypochlorite were used as chemical oxidants. Various strains of thionic bacteria A.ferrooxidans isolated from the initial ore of the Vasilkovsky deposit - strain 1 (experiment 3), heap leaching of the same deposit - strain 2 (experiment 4) and a laboratory strain - strain 3 (experiment 5) served as a biological oxidizer. In the process of biooxidation, the biological properties of these strains were studied in parallel, which directly determine their activity: changes in the pH of the medium, cell density, oxidizing properties (oxidation of Fe2 + to Fe3 +).

Conditions for preliminary chemical oxidation:

Experiment 1: sample mass 100 g (90% -0.044 mm), time 10 h, T: F = 1: 3, sodium peroxide - 10 g / l (in the presence of sulfuric acid 5%). The content of gold and impurities in the liquid phase after 10 hours: Cu - 0.14 mg / l; Fe-0.53 mg / l, oxidation-reduction potential (ORP) - 305 mV, pH = 1.85.

experiment 2: sample mass 100 g (90% -0.044 mm), time 10 h, T: F = 1: 3, calcium hypochlorite 10 g / l (in the presence of sulfuric acid 5%). The content in the liquid phase after 10 hours: Cu - 0.55 mg / l; Fe - 1.23 g / l, ORP - 310, pH = 1.8.

The conditions of preliminary biological oxidation for the three strains are the same:

- experiments 3,4,5: sample weight 100 g (90% -0,044 mm), preliminary flushing tailings washing out of traces of impurities (T: Ж = 1: 4; H2SO4 1-2%; temperature 25 ° C; h); bacterial oxidation of the washed cake (T: F = 1: 5, pH - 1.8-2.5, Fe3 + - 8.5 g / dm3, concentration of bacterial cells of A. ferrooxidans - 106 cells / ml, duration of biooxidation - 240 h with by continuous stirring on a shaker at 230 rpm). After biooxidation, the obtained cake was neutralized with an alkaline solution to pH-10.

- cyanide leaching of the pre-ground flotation tailings after preliminary chemical and biological oxidation was carried out under the following conditions: NaCN concentration 0.2%, T: F = 1: 3, duration 24 h. The process was accompanied by air supply.

As mentioned above, during the biooxidation process, the properties of the strains were studied in parallel, the following parameters were determined: pH change of the medium, bacterial cell density, and oxidation of the two-iron iron to the trivalent state. It should be noted that all three cultures were cultivated on synthetic medium 9K (Silverman and Lundgren). The results of the studies are shown in Figures 1, 2.

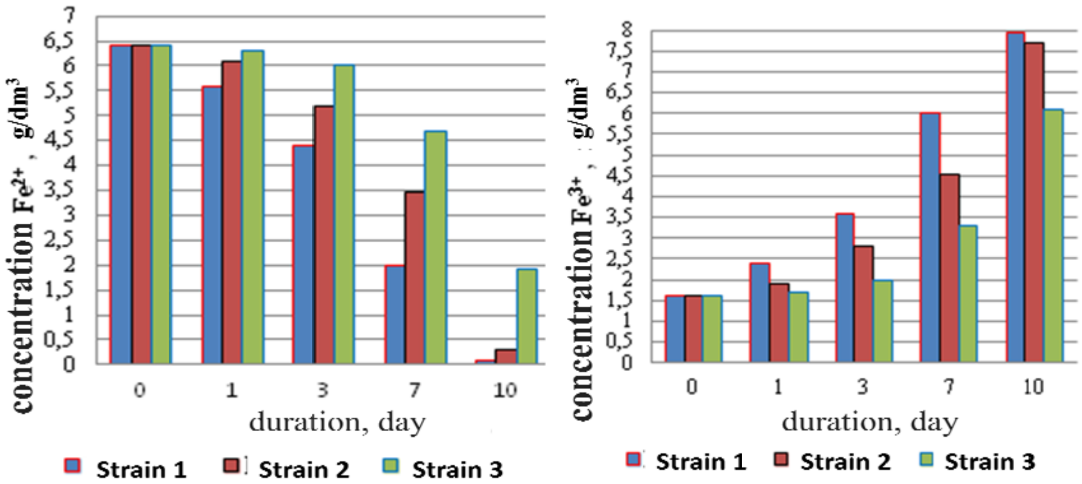


Figure 1 - The degree of iron oxidation (Fe^{2+} to Fe^{3+}) by thiobacteria in the process of biological recovery

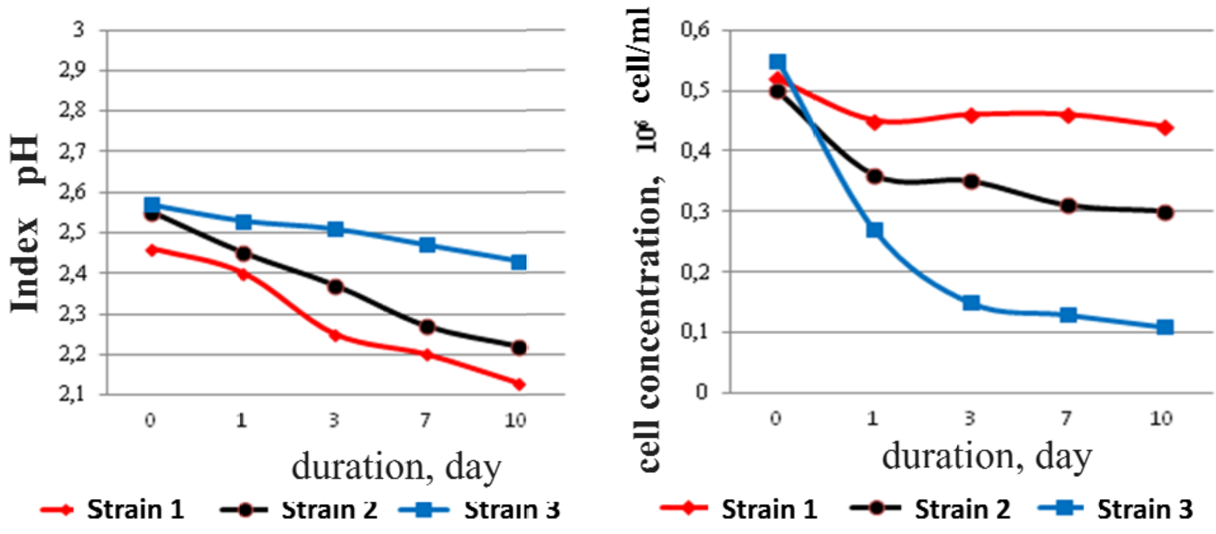
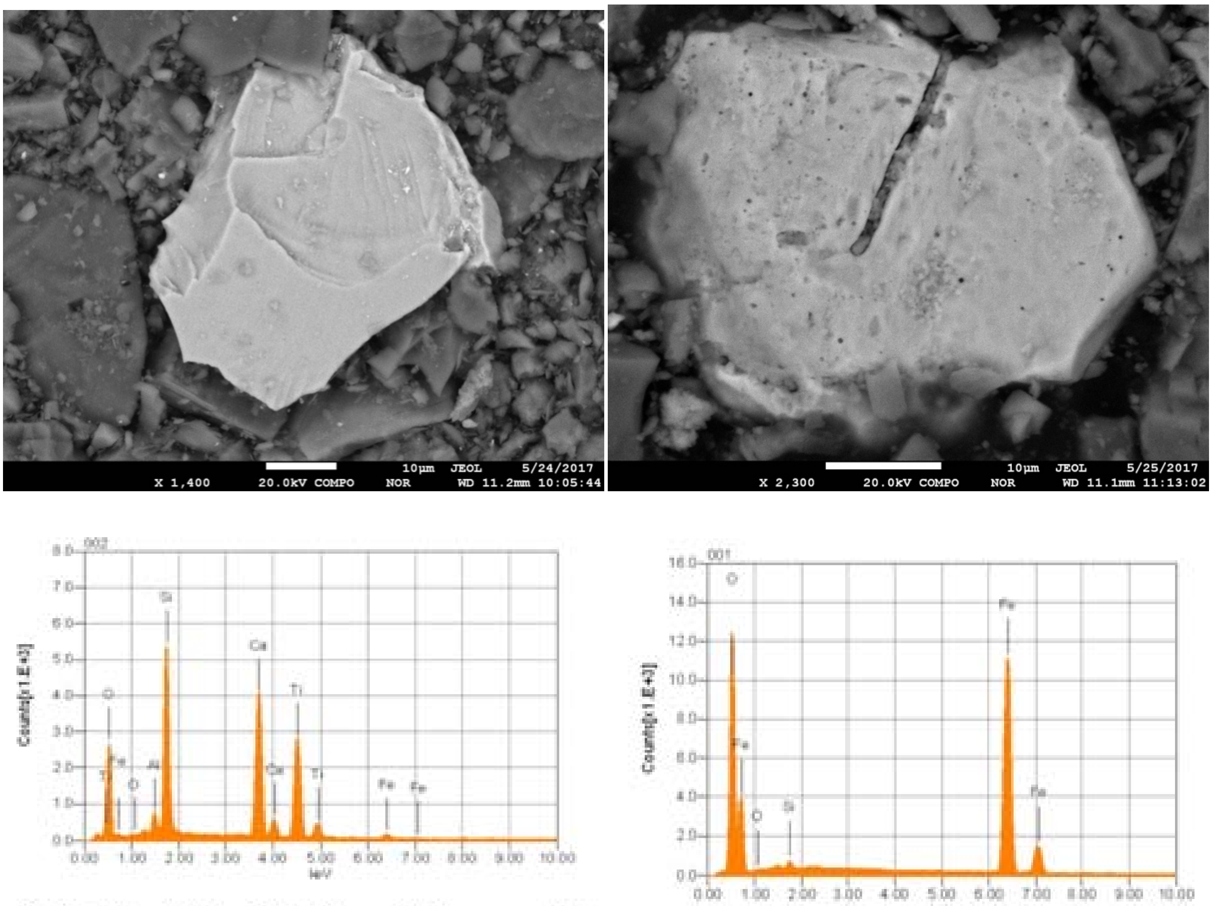


Figure 2 – pH change of medium and cell concentration during biological recovery

It follows from figure 2 that the oxidative properties of different strains, the criterion of which is the oxidation of Fe2 + to Fe3 +, differ from each other. The most active is strain 1. Oxidation of ferrous iron to the trivalent state with this strain is observed from the first day and further, as the process proceeds, almost complete oxidation of iron occurs on day 10. The residual concentration of bivalent iron after 10 days was 0.05 g / dm3. In the remaining strains on day 10, this indicator was equal to: strain 2 - 0.3 g / dm3 and strain 3 - 1.9 g / dm3.

It follows from Fig. 3 that in the process of biooxidation in solutions with strains 1 and 2 active medium is acidified. Initially, the pH of the medium was 2.46-2.56, after 10 days the pH was 2.13-2.14. The most active is strain 1. In strain 3, the pH value for the 10th day was 2.53. The process of cell growth and oxidation of iron for strain 3 is less active.

By the concentration of cells in solutions (Figure 3b), it can be concluded that strains 1 and 2 adapt well to flotation tailings: during the biooxidation process there were no abrupt contractions in the concentration of cells, a change in their concentration is very slow. The decrease in cell density in strains 1 and 2 is 15.4 and 40%, respectively, and the residual cell concentration in the solution is 84.6% in strain 1 and 60% in strain 2, which indicates the resistance of these strains to the test substrate.



Elements	ms%	mol%	Sigma	Net	K ratio	Line
O	47.42	68.60	0.55	455153	0.0662985	K
Al	1.31	1.13	0.13	132654	0.0052265	K
Si	11.73	9.66	0.13	1315571	0.0566898	K
Ca	17.42	10.06	0.19	1622893	0.1220649	K
Ti	20.19	9.76	0.27	1284795	0.1124351	K
Fe	1.93	0.80	0.49	73702	0.0109831	K
Total	100.00	100.00				

Initial sample

Elements	ms%	mol%	Sigma	Net	K ratio	Line
O	28.22	57.70	0.21	2070783	0.1914108	K
Si*	0.44	0.51	0.22	78826	0.0021555	K
Fe	71.35	41.79	0.62	6164146	0.5829165	K
Total	100.00	100.00				

Bio-cake

Figure 3 - REM analysis of the initial sample and bio-cake

In laboratory strain 3, the density of cells decreases sharply after the first day of contact with the flotation tail, then after 3 days the number of cells gradually decreases. When the concentration of cells decreases, the process of biooxidation of tailings of flotation proceeds at a very slow rate, which subsequently adversely affects the process of leaching of gold.

Thus, as a result of the biooxidation experiments, it was found that the most active among the studied cultures is strain 1 isolated from the Vasilkovsky ore, which showed rapid adaptation to the object under investigation-flotation tailings-in all respects.

Physicochemical studies of cake after biooxidation in the presence of strain 1, in particular X-ray phase analysis, showed that, compared to the initial sample, the microcline content in the cake was reduced (7.7 instead of 20.0%), and the resulting hydroxonium jarosite compound in the amount of 9.9%, the product of the vital activity of microorganisms formed in the process of biooxidation of the bivalent iron to the trivalent state. The content of other minerals entering the composition of the initial sample, such as anorthite, muscovite, riebeskite, clinochlore after biooxidation has not changed.

The results of the cake study after biooxidation by the SEM method are shown in figure 3.

As we can see in Figure 3, the structural morphological modifications took place in bio-cake in the form of the appearance of gaps and holes on the surface of a solid residue. It can be seen that the surface structure of the initial sample is smooth, without any morphological modifications, whereas in contrast, the topographic image of the bio-cake allows us to see the apparent structural modifications that were the result of the contact of bacteria with minerals, where in the subsequent, micro-destructions of crystal lattices occurred, where residual refractory gold is centralized.

After biological recovery, bio-cake was subjected to cyanide leaching in parallel in comparison with chemical oxidants. Table 2 shows parameters and indicators of experiments, as well as the results of tests for the determination of the effect of chemical and biological oxidants of regrinded samples on cyanidation parameters. The final results are comparatively shown in Figure 4.

Table 2 - Results for the determination of the effect of oxidants

Name of indicators	Control (without oxidation)	Test 1	Test 2	Test 3	Test 4	Test 5
Gold content in the initial sample, g/t	0.43	0.43	0.43	0.43	0.43	0.43
Quantity of solid phase of the sample, kg	0.1	0.1	0.1	0.1	0.1	0.1
Volume of liquid phase of pulp, L	0.3	0.3	0.3	0.3	0.3	0.3
NaCN concetration, %	0.2	0.2	0.2	0.2	0.2	0.2
Sodium cyanide consumption, kg/t	6.6	6.58	6.48	6.48	6.48	6.48
Consumed cyanide, kg/t	6.6	6.58	6.48	6.48	6.48	6.48
Gold content in leached tailings, g/t	0.13	0.12	0.11	0.12	0.14	0.265
Gold extraction from solid residue (cake),%	69.76	72.1	74.4	72.1	67.4	38.3

Experiment 1 - preliminary oxidation with hydrogen peroxide.

Experiment 2 - preliminary oxidation with calcium hypochlorite.

Experiments 3,4,5 - preliminary biooxidation in the presence of strains 1,2 and 3.

It follows from Figure 4 that the use of chemical oxidants prior to cyanidation increases the recovery of gold (72.1 and 74.4%) compared to direct cyanidation (69.76%). The result analogous to the preliminary oxidation with hydrogen peroxide (72.1%) demonstrates the biooxidation experiment with strain 1. The degree of gold recovery from cyanidation with pre-oxidation in the presence of strain 2 is lower than for direct cyanidation (67.4%), laboratory strain 3, showed the lowest gold recovery result (38.3). This fact is explained by the fact that strains 1 and 2 were extracted from the same field, where our objects - flotation tailings - were taken for research, so they quickly adapted to the material composition of the investigated object and the biooxidation process is much more intensive than with the use of bacterial cultures, extracted from other deposits.

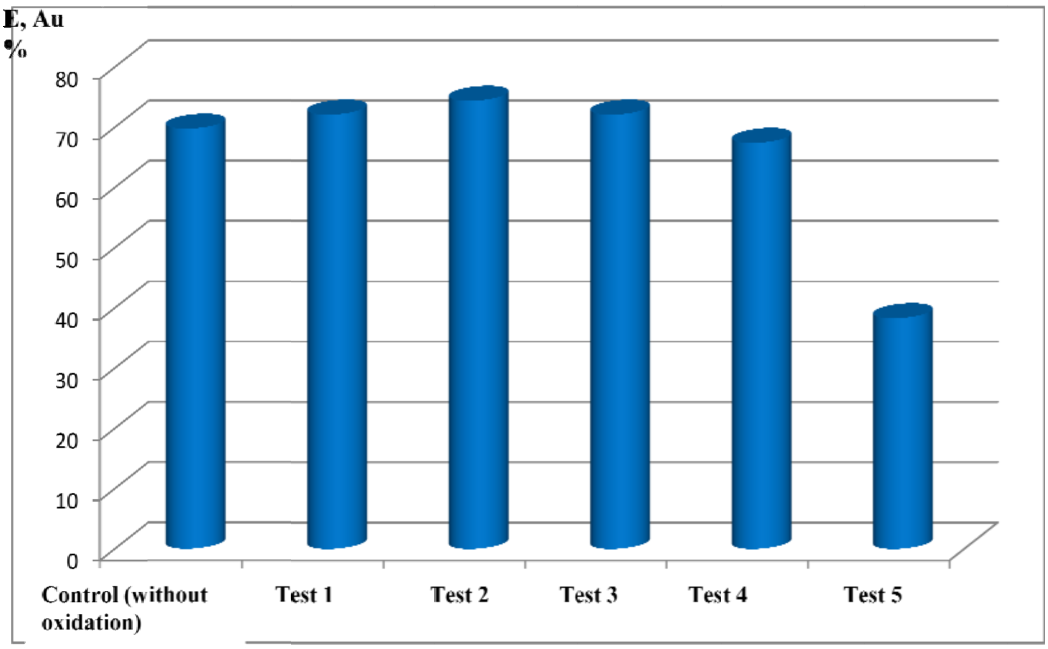


Figure 4 – (Biological and chemical) influence of various oxidants on the extraction degree of gold from flotation tailings

For the purpose of comparative study of gold recovery from tails of flotation, studies were conducted on cyanidation of tailings of enrichment tailings in the mineral processing department of the Federal State Unitary Enterprise "Central Research Geological Prospecting Institute of Nonferrous and Noble Metals" (FSUE TsNIGRI), Moscow, Russia.

In order to set up the experiments, a preliminary assay for gold was carried out from three parallel determinations from a sample material of initial size 0.074 mm. Analysis of the data obtained in the Institute for Determining the Gold Content in the Test Sample shows that the gold content in them is close to our data and is 0.367 g / t, whereas according to our results of the assay the initial sample contains 0.32 g / t gold .

Experimental conditions for sorption cyanidation of flotation tailings were carried out in the following mode: T: F = 1: 2, sodium cyanide concentration 0.1 %, pH = 10.5-11.0; loading resin AM-2B 5% by volume, temperature 20-25 ° C, duration 24 hours.

Analysis of the results of the study showed that the sample in question is poor and contains 0.367 g / ton of gold (average values of gold content in three parallel determinations by the assay method). The extraction of gold from poor flotation tailings by the method of sorption cyanidation is quite acceptable - 67.3% with a gold cyanide tailing loss of 0.12 g / t gold.

Conclusions

Thus, in the study of the cyanidation of pre-ground (0.044 mm) flotation tailings, it was established that with the preliminary oxidation by sodium peroxide, the degree of gold recovery during subsequent cyanidation is increased by 2 %, calcium hypochlorite - by 4.64 %, with bio-oxidation by an active strain of 1 bacterial culture this The indicator is higher by 2.34 % compared to direct cyanidation.

The conducted researches have shown that the use of oxidizing agents as intensifiers allows to increase the degree of pre-extraction of gold from man-made waste, bio-oxidation should be considered the most environmentally safe.

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АЛТЫН ӨНДІРУ ФАБРИКАЛАРЫНЫҢ ФЛОТАЦИЯ ҚАЛДЫҚТАРЫНАН АЛТЫНДЫ БӨЛІП АЛУ

Аннотация. Флотация қалдықтарын өкілдік үлгісі алынып оның химиялық, фазалық және минералогиялық құрамы тексерілді. Алтынның кварцпен байланысы бар екендігі көрсетіліп, негізі дисперсті түрде, ол жағдайдың мұқият іріктелуін және оны қалай алу керектігін талап етеді. Зерттеулер барысында қалдықтардың тікелей цианидтеу, сондай-ақ, оксиданттардың алдын-ала қолданылуы жүзеге асырылды. Химиялық реагенттермен тотығу - натрий пероксиді және кальций гипохлориті және әртүрлі биоштамдары қолданылды. Зерттеулер көрсеткендей, қалдықтарды алдын-ала қайта өңдеу және қышқылдау тотығу кейінгі цианидация сатысында алтынның шаймалау дәрежесін тікелей цианидпен салыстырғанда 2,34% -ға арттыруға мүмкіндік береді.

Ең тиімді тотықтырғыш кальций гипохлориті болып табылады, содан кейін биоксынамалар мен натрий пероксидінің тотығу күйін бақылап отырады, минералды шөгінді кен орнының флотациялық қалдықтарымен оқшауланған, ең белсенді тотықтырғыш болып табылады, сондықтан микроорганизмдер зерттелетін заттың материалды құрамына жылдам бейімделіп, басқа кен орындарынан оқшауланған бактериялық сынамаларды пайдалануға қарағанда биототықтыру процесі әлдеқайда қарқынды жүреді.

Электронды-растрлық микроанализ әдісімен биототығудан кейінгі зерттеу нәтижелері (РЭМ) бастапқы құрылымға қатысты өзінің құрылымында көрінетін өзгерісті көрсетті: биототығудан кейін пайда болған тесіктер мен тесіктер топографиялық кескінде анық көрінеді. Құрылымдағы осындай өзгерістердің нәтижесінде тау жыныстарының минералдары бар алтынның облигацияларының бұзылуы және соның салдарынан цианидтеу алтынның шаймалау деңгейін жоғарлатады.

Жасалған зерттеулердің нәтижесінде интенсификатор ретінде қолданылған тотықтырғыштар техногенді қалдықтардан алтын алу көрсеткішін жоғарлатады және биототықтыру экологияға зардапсыз.

Тірек сөздер: алтын, флотация қалдықтары, биототықтыру, цианидтеу, гидрометаллургия.

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ДОИЗВЛЕЧЕНИЕ ЗОЛОТА ИЗ ОТВАЛЬНЫХ ХВОСТОВ ФЛОТАЦИИ ЗОЛОТОИЗВЛЕКАТЕЛЬНЫХ ФАБРИК

Аннотация. Отобрана представительная проба отвальных хвостов флотации и изучены ее химический, фазовый и минералогический состав. Показано, что золото находится в ассоциациях с кварцем, и присутствует, в основном, в тонкодисперсном виде в сростках, что требует тщательного выбора условий и способа его извлечения. В ходе исследований было проведено прямое цианирование хвостов, а также с предварительным воздействием окислителей. Применяли окисление химическими реагентами - пероксидом натрия и гипохлоритом кальция и разными штаммами биокультур. Исследования показали, что предварительное доизмельчение и окисление хвостов позволяет повысить степень выщелачивания золота на стадии последующего цианирования на 2,34 % по сравнению с прямым цианированием.

Наиболее эффективным окислителем является гипохлорит кальция, далее по степени окисления следуют биокультуры и пероксид натрия, причем более активным окислителем является штамм биокультур, выделенный из одного с хвостами флотации месторождения, ввиду чего микроорганизмы быстро адаптируются к вещественному составу исследуемого объекта и процесс биоокисления происходит намного интенсивнее, чем при использовании бактериальных культур, выделенных из других месторождений.

Результаты исследования кека после биоокисления методом электронно-растрового микроанализа (РЭМ) показали видимые изменении в его структуре относительно исходного сырья: после биоокисления на топографическом снимке явно видны образовавшиеся щели и отверстия. Результатом такого изменения структуры является разрушение связей золота с породообразующими минералами и как следствие – повышение степени выщелачивания золота при цианировании.

Проведенными исследованиями установлено, что применение окислителей в качестве интенсификаторов позволяет повысить степень доизвлечения золота из техногенных отходов, наиболее экологически безопасным следует считать биоокисление.

Ключевые слова: золото, хвосты флотации, биоокисление, цианирование, гидрометаллургия.

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