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HYDROMETALLURGICAL PROCESSING OF PERSISTENT GOLD-BEARING ORES BY TRADITIONAL BENEFICATION METHODS

Abstract: Based on the analysis of the results of physical and chemical research, known methods and techniques for processing low-grade gold-containing raw materials have been offered and tested, the application of which will allow the most complete transfer of gold into solution. In the course of physical-chemical studies of the initial ore, such methods as X-ray diffraction X-ray fluorescence, mineralogical and chemical methods are used, in addition, using the assay method, the characteristics of the forms of finding gold in raw materials are given. According to X-ray phase analysis, the initial ore belongs to the siliceous type, which is confirmed by X-ray fluorescence and chemical analysis methods. The content of silicon in the ore is 28.8 %, which in terms of silicon oxide is about 62 %. The gold content is 1.02 g/t. The mineralogical analysis of the raw material showed that ore mineralization of gold is pyrite, and according to the assay there is practically no visible native gold in the ore, its content is 1.1 %, the fine-dispersed in the rock-forming minerals is 77.8 %. The following ore processing methods were tested: direct cyanidation, gravity enrichment with subsequent cyanidation, flotation enrichment followed by cyanidation. The recovery of gold under direct cyanidation was 70.6 %, under conditions of gravity ore enrichment, followed by cyanidation – 75.5 %. Cyanide leaching of the flotation concentrate allowed to convert 63.0 % of gold into the solution. Based on the results of the conducted studies low-grade ore of the Karyernoye deposit is recommended processing by cyanide leaching with preliminary gravitational concentration.

Key words: gold-bearing ore, gravitation concentrate, flotation concentrate, cyanidation, hydrometallurgy

Introduction. In connection with the depletion of light-weight gold-bearing ore reserves, the industry faces the task of involving low-grade raw materials in production. This is, as a rule, off-balance, stubborn and technogenic raw materials [1-3].

On the territory of the Republic of Kazakhstan there is a number of the world's largest deposits of non-ferrous and precious metals whose ores, due to the peculiarities of their chemical and phase composition, can not be profitably processed by existing methods, and therefore are classified as off-balance [4-8]. The reserves of this kind of raw materials are significant, and therefore, the development of an efficient technology for extracting gold from it on the basis of available methods and techniques is becoming increasingly relevant.

The purpose of these studies was to determine the priority options for processing low-grade raw materials at the Karyernoye deposit.

Experimental part and results discussion. Studies of the initial sample by the X-ray phase analysis method determined the main constituents of the sample, which are quartz and albite (Table 1)

Table 1 – Phase composition of the initial sample

Mineral	Chemical formula	S-Q, %
Quartz, syn	SiO_2	65,9
Albite	$Na(AlSi_3O_8)$	13,8
Muscovite-2M1	$(K,Na)(Al,Mg,Fe)_2(Si_3.1Al_{0.9})O_{10}(OH)_2$	6,2
Gypsum	$Ca(SO_4)(H_2O)_2$	5,3
Pyrite, arsenical	$Fe(S_{0.72}As_{0.28})_2$	4,5
Calcium Carbonate	$CaMg(CO_3)_2$	4,3

According to the chemical composition, the initial ore is represented by the following components, %: 65,9 – SiO_2; 6,35 – Fe_2O_3; 1,98 – SO_4; 0,44 – Fe_{oc}; 0,66 – $S^{2+}_{(sulphate)}$; 0,03 – $S^{2-}_{(sulfide)}$; 0,37 – $C_{total.}$; <0,1 – $C_{org.}$; 1,0 g/t – Au, and according to X-ray fluorescence analysis - has the following elemental composition, %: 28,8 – Si; 55,3 – O; 6,6 – Al; 0,69 – S; 2,5 – Na; 1,45 – K; 2,65 – Fe; 0,11 – As; 0,95 – Ca; 0,25 – Ti; 0,35 – Mg; 0,03 – P; 0,02 – Mn; 0,02 – Cl; 0,01 – Sr; 0,005 – V; 0,009 – Cr; 0,006 – Cu; 0,006 – Zn.

Thus, the data of X-ray phase, X-ray fluorescence and chemical analysis methods showed that the main valuable component of the sample is gold, the content of which is 1.02 g/t.

In order to determine the ore mineralization of gold, a mineralogical analysis of the feedstock was carried out, which showed that the ore consists of altered sandstones (quartz-carbonate), aleurosandstones and siltstones with veins of quartz, carbonate-quartz composition bearing scattered dissemination of pyrite. The technological sample is characterized by a disseminated type gold-sulphide-quartz formation. Ore mineralization of gold is pyrite.

A characteristic analysis of the forms of gold finding and the nature of its relationship with ore components gives a rational analysis, according to which almost no visible native gold is found in the ore, its content is 1.1 %, fine-grained gold in rock-forming minerals is represented by 77.8 %.

Based on the analysis of the results of physical and chemical studies, the following options for processing the initial ore were proposed and tested:

- direct cyanidation;
- gravitational enrichment with subsequent cyanidation;
- flotation enrichment with subsequent cyanidation.

In the process of direct cyanidation, the initial ore was crushed to a particle size of -0.071 mm, 80 % in the first and 90 % in the second variant. Cyanidation was conducted by campaigning with air aeration. In all cases, the duration of the experiments was 24 hours, the volume of the solution was 400 ml, all experiments were carried out under air supply conditions. The initial mass of the ore was 100 g, the ratio of S: L = 1: 4, the temperature was maintained at 20 °C. The concentration of sodium cyanide was 0.05 and 0.1 %. The results are shown in Table 2. It follows from the table that the degree of gold recovery into the solution during direct cyanidation varies from 62.7 to 70.6 %, depending on the leaching conditions.

Table 2 - Results of direct cyanidation of the initial ore

Conditions and results of the process	Indicators			
	80 % – 0.071 mm		90 % – 0.071 mm	
	Test 1	Test 2	Test 1	Test 2
Sample weight, g	100	100	100	100
Volume of solution, ml	400	400	400	400
Concentration of NaCN, %	0,05	0,1	0,05	0,1
pH	10,7	10,9	10,8	11,1
Duration, hours	24	24	24	24
With air supply	+	+	+	+
Au content in initial ore by assay analysis, g/t	1,02	1,02	1,02	1,02
Au content in the cake, g/t	0,38	0,3	0,32	0,33
Degree of Au extraction by cake, %	62,7	70,6	68,6	67,6

Gravitational enrichment was carried out with pre-crushed ore to a size of 75 microns in three stages. The enrichment results are presented in Table 3. It follows from the table that in the enrichment process a gravitational concentrate with a yield of 12.31 % was obtained with a gold content of 14.31 g/t and an extraction of 45.5 %. At the same time, the yield of tailings was 87.69 % with a gold content of 2.4 g/t and recovery of 54.5 %.

Table 3 - Results of gravitational enrichment

Product name	Yield, %	Au, g/t	E of Au, %
Concentrate of recleaning	12,31	14,31	45,5
Tails of recleaning	87,69	2,4	54,5
Total	100,0	3,87	100,0
E - degree of Au extraction			

The resulting gravity concentrate with a gold content of 14.31 g/t was supplied to leaching with sodium cyanide, a concentration of 0.2 %. The leaching was carried out at pH 11.2 in the aeration mode for 24 hours. The results obtained are shown in Table 4.

Table 4 - Results of cyanidation of gravy concentrates

Conditions and results of the process	Indicators
	2 stage concentration after purification
Sample weight, g	50
Volume of solution, ml	200
Concentration of NaCN, %	0,2
PH	11,2
Duration, hours	24
With air supply	+
Au content in initial concentrate by assay analysis, g/t	14,31
The Au content in the cake after leaching, g/t.	3,5
Extraction rate of Au, %	**75,5**

As can be seen from the table, during the cyanidation of the gravy concentrate, gold recovery into the solution was 75.5 %.

Flotation concentrating was performed on standard laboratory flotation machines of the «Mekhanobr» type with a chamber volume of 1.5; 0.5 and 0.25 dm^3 in three stages in closed mode. The following reagents were used: butyl xanthate - collector, activity according to the certificate 84.5 %; T-80 - blowing agent, activity 100 %; Vitriol copper - activator, activity 65 %; Sodium sulphide - activator, activity 100 %. The process was carried out at pH 7-7.5. The results obtained are presented in Table 5.

It follows from the table that gold was distributed between the concentrate and tails, respectively, 47.43 and 52.57 %. The yield of gold-bearing concentrate was 3.48 % with gold content of 13.26 g/t, and tailings yield - 96.52 % at a content of 0.53 g/t.

Table 5 - Results of flotation enrichment.

Product	Yield, %	Content, g/t Au	Extraction, % Au
Concentrate	3,48	13,26	47,43
Tails	96,52	0,53	52,57
Ore	100	0,97	100,00

Further, the flotation concentrate was subjected to ultrathin grinding in a bead mill to a fineness (P) of 80 to 10 μm, then its cyanidation was performed at parameters similar to the cyanation of the initial process sample. The results of cyanidation of the flotation concentrate are shown in Table 6.

Table 6 - Results of cyanidation of the flotation concentrate

Conditions and results of the process	Indicators
Sample weight, g	50
Mass of solution, ml	200
Concentration of NaCN, %	0,2
pH	11,3
Duration, hours	24
With air supply	+
Au content in initial flotation concentrate by assay analysis, g/t	13,26
Au content in the cake, g/t	4,9
Extraction rate of Au, %	**63,0**

As a result of the use of flotation enrichment and hydrometallurgical processing of the flotation concentrate, the total extraction of gold was 63.0 %.

Thus, the conducted studies showed that the degree of gold recovery into the solution in direct cyanidation varied from 62.7 to 70.6 % depending on the process conditions, while leaching of the gravy concentrate was - 75.5, and of the flotation concentrate - 63.0 %.

Conclusions. The material composition of the Karyernoye deposit ore‘s is technological sample was studied. X-ray phase, X-ray fluorescent, crystal-optical and chemical analyzes of the initial ore were performed, and the phases of gold present were assayed by the sampling method.

Based on the results of physicochemical studies of the initial ore, the following processing options were tested: direct cyanidation, gravity enrichment followed by cyanidation, flotation enrichment followed by cyanidation.

The maximum extraction of gold under conditions of direct cyanidation was 70.6 %, in conditions of gravity concentration of ore with subsequent cyanidation – 75.5 %. Cyanide leaching of the flotation concentrate allowed the conversion of 63.0 % gold into the solution.

Based on the results of the conducted studies of low-grade ore of the Karyernoye deposit is recommended to be processed by cyanide leaching with preliminary gravitational concentration.

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ТҮЙІНДЕМЕ

Физика-химиялық талдау нәтижелері бойынша төмен сұрыпты алтыны бар кендерді өңдеу үшін алтынды толықтай ерітіндіге өткізуге болатын белгілі әдістері мен тәсілдерін ұсынды.Бастапқы кенді физико-химиялық элементтік,РФА, минерологиялық және химиялықлық зерттеуде алтын кенде қандай түрде екені анықталды. РФА айтуынша бастапқы кен кремнийлі түріне жатады. Элементтік және химиялық талдау әдістері растады. Кендегі кремний көрсеткіші 28,8 %, кремний тотығына есептегенде шамамен 62 % құрайды. алтын көрсеткіші - 1,02 г / т. Пробирлі талдаудың нәтижесінде кеннің құрамында ешқандай көрінетін алтын жоқтың қасы, оның көрсеткіші 1,1 %, майдалап ұсақталған минералды алтын 77,8 %, минералогиялық талдау нәтижесінде шикізат минералды алтын пирит екенін көрсетті, және талдауға сәйкес шықты. Кенді өңдеудің әр түрлі нұсқалары сыналды:тікелей цианидтеу, гравитациялық байытып цианидтеу, флотациялық байытып цианидтеу,. тікелей цианидтеу алтын өндіру кендерін -70,6 % -ға, гравитациялық байытып барып цианидтеу 75,5 % құрады. Флотоконцентратты цианидпен шаймалағанда ерітіндіге алтынды 63,0 % өткізді. Зерттеулер қорытындысында Карьерное жерінің төмен сұрыпты кенін алдымен гравитациялық байытып барып цианидеу қажет.

Түйінді сөздер: алтын құрамды кен, гравиоконцентрат, флотоконцентрат, цианидтеу, гидрометаллургия

РЕЗЮМЕ

На основании анализа результатов физико-химических исследований предложены и опробованы известные способы и приемы переработки низкосортного золотосодержащего сырья, применение которых позволит наиболее полно перевести золото в раствор. В ходе физико-химических исследований исходной руды применены такие методы как рентгенофазовый, рентгенофлюорисцентный, минералогический и химический, кроме того, с помощью пробирного метода дана характеристика форм нахождения золота в сырье. Согласно рентгенофазовому анализу исходная руда относится к кремнистому типу, что подтверждено рентгенофлюорисцентным и химическим методами анализа. Содержание кремния в руде равняется 28,8 %, что в пересчете на оксид кремния составляет около 62 %. Содержание золота – 1,02 г/т. Проведенный минералогический анализ исходного сырья показал, что рудной минерализацией золота является пирит. Согласно пробирному анализу в руде практически отсутствует видимое самородное золото, его содержание составляет 1,1 %, тонкодисперсное в породообразующих минералах представлено 77,8 %. Опробованы следующие варианты переработки руды: прямое цианирование, гравитационное обогащение с последующим цианированием, флотационное обогащение с последующим цианированием. Извлечение золота в условиях прямого цианирования составило 70,6 %, в условиях гравитационного обогащения руды с последующим цианированием – 75,5 %. Цианидное выщелачивание флотоконцентрата позволило перевести в раствор 63,0 % золота. На основании результатов проведенных исследований низкосортную руду месторождения Карьерное рекомендуется перерабатывать цианидным выщелачиванием с предварительным гравитационным концентрированием.

Ключевые слова: золотосодержащая руда, гравиоконцентрат, флотоконцентрат, цианирование, гидрометаллургия

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