MINERALS BENEFICATION

UDC 669.334.3 **Complex Use of Mineral Resources. No 3. 2017**

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ESTIMATION OF GOLD-BEARING PERSISTENT ORES FLOTATION BENEFICATION EFFICIENCY BY HANCOCK-LOUIKEN CRITERION

Abstract: A sample of the refractory gold-containing ore of the Karernoye deposit was subjected to a stage crushing up to -0.071+0 mm of grain size grade, followed by separation and averaging in accordance with the standard sampling technique for technological studies and material composition reseraches. According to the chemical analysis, the average gold content the sample is 1.02 g/t. The content of other elements and their compounds is as follows, %: Fe_2O_3 – 5,3; Fe_{ox} – 2,17; SO_4^{2-} – 0,045; S^{2+} – 0,015; S^{2-} – 0,865; C_{total} – 1,87; $C_{org.}$ < 0,1. Mineralogical and electron microscopic methods of analysis shown that gold in this sample is presented mainly in the form of sulfide which are intergrowths with pyrite and microparticles interspersed into quartz and sandstone. The results of flotation washability of the refractory ore according to the classical scheme in a closed cycle with 3 re-cleaning operations are presented. As a result of flotation benefication of the studied ore, the conditioned flotation concentrate was obtained with a gold content of 26.68 g/t (as per technical regulations requirements it is more than 20 g/t), with a mass yield of 3.48 % and gold recovery into the concentrate 91,0 %. In flotation tailings, the gold content is less than 0.09 g/t, which is about 9 % of gold. The efficiency of the flotation process was calculated using the Hancock-Louiken formula, the efficiency coefficient η was: η = 87.5 %, high efficiencies η > 75 %, indicates that the flotation process is very effective, which is also confirmed by the high values of the coefficients of enrichment ($K_{conc.}$ = 26.2) and reduction (R = 28.7). Taking into consideration the complicated composition of the flotation concentrate by harmful impurities (arsenic, antimony and organic carbon) and a high content of sulphide sulfur in the form of pyrite, the process of its further processing by direct cyanidation will be ineffective. In this case one of the options for processing the flotation concentrate may be a preliminary chemical oxidation method of sulphides before cyanidation.

Key words: resistant ore, flotation benefication, enrichment factor, reduction factor, enrichment efficiency, Hancock-Louiken criterion

Introduction. At the present time, the metallurgical industry faces the problem of a negative tendency towards share increase of sulphide, off-balance, complex in chemical composition resistant gold-bearing ores in the total volume of processed raw materials. This is related to a decrease in the reserves of the most accessible and lightly-conceived ores and an increase in the proportion of gold-containing ores and concentrates, the treatment of which in conventional cyanide processes does not provide a sufficiently high degree of gold recovery [1].

In the middle of the 50s, in the territories of many CIS republics, geological samples from new deposits and deeper horizons of known deposits were studied, previously unknown in terms of the geological structure and features of the material composition of the vein-interspersed ore; gold-sulfide deposits, represented by mineralized zones and deposits in sedimentary and volcanogenic-sedimentary rocks. Gold in ores is associated primarily with sulphides (pyrite, arsenopyrite, chalcopyrite, etc.), with iron oxides and arsenates (limonite, scorodite, etc.), while a significant (more than 20 %) part of it is in finely dispersed form. Despite the significant number and large scale of deposits of this type explored in subsequent years, their exploitation is hampered to the present because of the persistent nature of primary sulphide ores, the processing of which requires the use of special expensive technologies. [2-5].

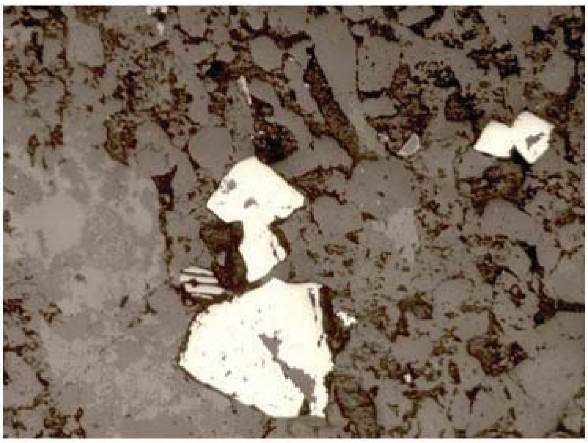
The development and reclamation of technology for extracting gold from accumulated technogenic mineral objects, primarily from refractory gold-containing ores, as well as from the dumps and tailings of gold recovery factories and industries, acquires special significance for many gold mining enterprises whose raw stock of conditioned ore is close to exhaustion. In this regard, the rationale of this research area is subjected to the presence in our country of a large number of poor and refractory gold-containing ores that are not currently processed [6, 7]. The object of this study was the refractory gold-containing ore of the Karjernoye deposit.

The purpose of this work is the study of flotation enrichment of a refractory gold-containing ore and efficiency process calculation using the Hancock-Louiken formula [8-10].

Experimental part and discussion of the results. To study the technological properties of the sample of the Karjernoye deposit, a sample of the initial ore, represented as a core, with a particle size of 5 to 15 cm was selected. After averaging and quarting, the sample was crushed on a jaw and roll crusher, followed by grinding to a size of -0.071 mm on a ball mill. Before the experiments start, the sample was sent for chemical, mineralogical, phase and electron microscopic analyzes.

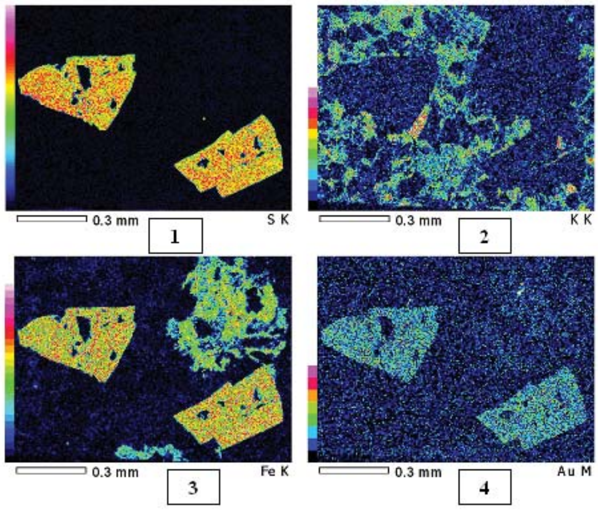
According to the chemical analysis, the average gold content of the sample is 1.02 g/t. The content of other elements and their compounds was also determined as follows, %: Fe_2O_3 – 5,3; Fe_{ox} – 2,17; SO_4^{2-} – 0,045; S^{2+} – 0,015; S^{2-} – 0,865; C_{total} – 1,87; $C_{org.}$ < 0,1.

Mineralogical analysis of the sample revealed a predominance of impregnations of pyrite and arsenopyrite in sandstone (Figure 1). According to the mineralogical and phase analysis, no visible native gold was found in the sample. However, a detailed study of minerals on an electron probe microanalyzer revealed the presence of microinclusions of gold in pyrite (Figure 2a, b). In accordance with Figure 2, the grains of arsenic pyrite in the sulfide sample, taken in the EDS regime with magnifications of 65 (a) and 250 (b), contain gold particles. Thus, in photographs 4, "invisible" gold in pyrite is recorded. The grain size of the latter is 0.437x0.563 μm., That is 437x563 nanometers, 0.469x0.469 μm, 0.258x0.328 μm, 0.141x0.164 μm and 0.023x0.023 μm. The obtained results indicate the formation in this sample of mineralogy of submicroscopic ("invisible") gold [2].

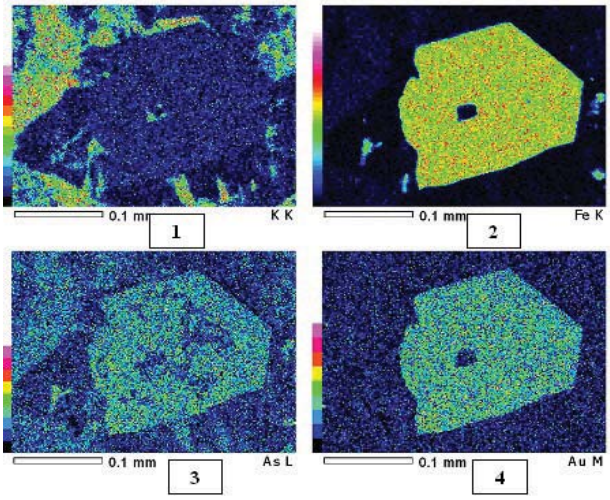


anshlif an increase of x 100

Figure 1 – Pyrite dissemination in sandstone



a – increase of x 65



b – increase of x 250

Figure 2 – Grains of arsenic pyrite in a sulfide sample, photographed in EDS mode S.

The results of mineralogical and electron microscopic studies shows that gold in this sample is in a sulphide form in the type of intergrowths with pyrite and interspersed with quartz and sandstone. Ores with such forms of gold finding are difficult to enrich and require the use of specific combined methods of extracting a useful component, with additional hydro- and pyrometallurgical refinements.

Flotation and operating time of flotation concentrate according to the optimal regime were carried out on standard laboratory flotation machines of the "Mekhanobr" type with a chamber volume of 0.5; 1.0 and 3.0 dm^3.

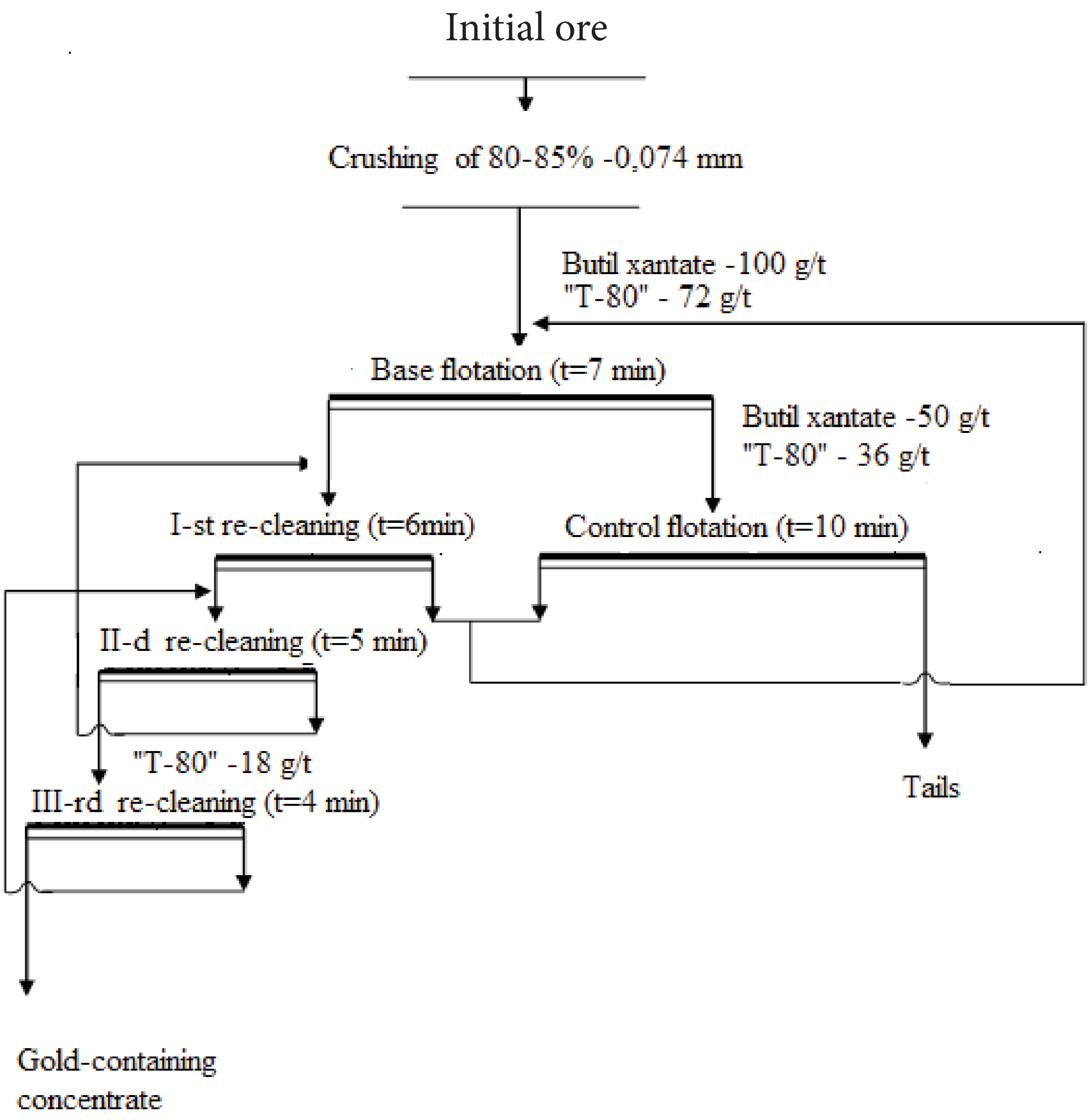


Figure 3 – Scheme of ore flotation in a closed cycle

Flotation was carried out on tap water at pH 7-7.5 in a closed cycle with 3 cleanings at a pulp density of 30 %, according to the scheme shown in Figure 3.

Flotation was carried out using the following reagents:

- butyl xanthate - collector, activity on the certificate is 84.5 %;
- T-80 - blowing agent, activity 100 %;
- vitriol copper - activator, activity 65 %;
- sodium sulphide - activator, activity 100 %.

As a result of flotation enrichment of ore with an initial content of 1.02 g/t, a conditioned flotation concentrate with a gold content of 26.68 g/t was obtained, with a mass yield of 3.48 %, recovery to the concentrate of 91.0 %. In the tails with a content of 0.09 g/t, 9 % of gold remained. Flotation results are shown in Table 1.

Table 1 – Results of flotation enrichment in a closed cycle

Products name	Yield, %	Content, g/t	Extraction, % Au
Concentrate of the final stage	3,48	26,68	91,0
Tails	96,52	0,09	9,0
Ore	100	1,02	100,00

The chemical analysis of the flotation concentrate also showed the presence of the following elements and compounds, %: SiO_2 – 35.65; Al_2O_3 – 9.25; As – 1.75; Sb – 0.004; C_{total} – 12.6, C_{org} – 0.14. The content of total sulfur in the concentrate reaches 32 % and almost all of it (more than 99 %) is associated with pyrite (FeS_2) according to the data of phase-phase analysis. The chemical composition of the obtained gold-containing flotation concentrate satisfies the technical specifications for flotation concentrates TU 48-16-6-75, which are shown in Table 2.

Based on the experimental data, the efficiency of the flotation process was calculated.

The beneficiation factor (or concentration - $K_{enrich.}$) has been calculated by the following formula:

$K_{benefic.} = W_{conc..}/W_{ore.}$,

where $W_{conc.}/W_{ore}$ – mass fractions of the useful component in the concentrate and in the initial ore, respectively, and was in this case: $K_{benefic.} = 26,68/1,02 = 26,2$;

Table 2 – Parameters of TR 48-16-6-75 - for flotation gold-bearing concentrates

Name of concentrate	Content				Humidity, %
	Gold not less than, g/t	Impurities, %			
		Arsenic	Antimony	Alumina	
Gold-containing flotation concentrate	20,0	2,0	0,30	10,0	6,0

The coefficient of reduction (R), characterizing the quantitative reduction of the mass of the concentrate in comparison with the mass of the ore, was calculated by the formula:

$R = 100 / \beta_{conc.}$

where $\beta_{conc.}$ – yield of concentrate in %,

and equaled: R =100/3,48 = 28,7.

The efficiency of ore beneficiation by flotation was calculated using the Hancock-Louiken formula [8-10]:

$\eta = (\varepsilon - \gamma_{conc.}) \cdot 100/(100-\alpha)$,

where η is a coefficient (criterion) of efficiency, %

ε – extraction rate, %,

$\gamma_{conc.}$ – yield of concentrate, %,

α – the content of the useful component in the initial ore, %.

Estimated value equaled:

$\eta = (91-3,48) \cdot 100 / (100-0,0001) = 87,5$ %.

At values of the Hancock-Louiken coefficient η > 75 % the enrichment process is considered very effective, because at values greater than 50 % effective and at 25 % ineffective. In this case, we can consider the flotation tests to be very effective, which is also confirmed by the high values of the coefficients of enrichment ($K_{benefic}$ = 26.2) and reduction (R = 28.7).

Taking into consideration the complex composition of the flotation concentrate for harmful impurities (arsenic, antimony and organic carbon) and a high sulfur content of sulphide in the form of pyrite, the process of its further processing by direct cyanidation will be ineffective. Processing of concentrates of this type is possible by known methods: pre-treatment of concentrates by calcination, autoclave oxidation in acid media, chemical or biooxidation.

The processing of the obtained flotation concentrates can also be carried out by pyrometallurgical methods. In this case, it is conducted jointly with the main raw materials at the non-ferrous metallurgy plants.

Conclusions. It is determined that gold in the samples of this ore is in a thin-grained state in iron sulfides.

Due to these properties, gold is well extracted in flotation enrichment to produce a high-quality flotation concentrate. The flotation method allowed to concentrate gold in a rich product, the yield of flotation concentrates was 3.48 %. The initial gold content of 1.02 g/t in the ore increased to 26.88 g/t in the concentrate, while gold recovery was 91 %.

The Hancock-Louiken coefficient, which characterizes the efficiency of enrichment, equaled 87.5 %, which indicates that the flotation enrichment of this ore is very effective, this is also confirmed by the high values of the enrichment coefficients ($K_{benefic}$ = 26.2) and the reduction (R = 28.7).

The admixtures of arsenic, antimony and organic carbon, found during the chemical analysis, will complicate the process of subsequent cyanidation. The harmful effect of these impurities can be eliminated by pretreatment of concentrates by calcination, autoclave oxidation in acid media, chemical or biooxidation.

The processing of the obtained flotation concentrates can be carried out using pyrometallurgical methods. Then it is carried out together with the main raw materials at the non-ferrous metallurgy plants.

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ТҮЙІНДЕМЕ

Карьерное кен орнының өңделуі қиын алтыны бар кендерінің үлгілері зерттелді, ол бөлшектердің өлшеміне -0,071 + 0 мм-ге дейін ұсақталды, содан кейін бөліну, стандартты үлгілеу техникасына сәйкес технологиялық зерттеулер мен материалдарды құрамдық анықтау. Химиялық талдауға сәйкес үлгідегі алтынның орташа мөлшері 1.02 г/т құрайды. Басқа элементтердің және олардың қосылыстарының құрамы мынадай, %: Fe_2O_3 – 5.3; $Fe_{ок}$ – 2.17; SO_4^{2-} – 0.045; S^{2+} – 0.015; S^{2-}– 0.865; $C_{общ}$ – 1.87; $C_{ок}$ < 0.1. Минералогиялық және электронды микроскопиялық талдау әдістері бұл үлгідегі алтын негізінен кварц пен құмтаспен араласқан пирит және микробөлшек, кварц пен құмтаста кездеседі. Өңделуі қиын кендердің жабық циклда үш рет флотациялық байытудың классикалық сызбасы көрсетілген.Флотациялық байытудың нәтижесінде зерттелген кеннен кондициялық флотациялық концентрат алынды. Құрамындағы алтынның мөлшері 26,68 г/т (20 г/т артық талап етілетін ТК талаптары), ал массасы бойынша кірістілік 3,48 %, тазарту концентратына алтынның алыну мөлшері 91,0 % құрады. Флотация қалдықтарының құрамындағы алтынның мөлшері 0.09 г/т кем, бұл шамамен 9 % алтын. Флотация процесінің тиімділігі Ханкок-Луйкен формуласы бойынша есептелген, тиімділік коэффициенті р: η = 87,5 %, жоғары тиімділігі > 75 %, флотация процесі өте тиімді екенін көрсетеді, бұл коэффициенттердің жоғары мәндерімен расталады байыту ($K_{обог}$ = 26.2) және азайту (R = 28.7). Флотациялық концентраттың күрделі құрамын зиянды қоспалар (мышьяк, сурьма және органикалық көміртегі) және күкірттің құрамында пиритті түрінде алу арқылы оны тікелей цианидпен өңдеу әдісі тиімсіз болады. Бұл жағдайда флотационды концентратты өңдеудің бір нұсқасы сульфидтерді цианидацияға дейін алдын-ала химиялық тотықтыруға арналған әдіс болуы мүмкін.

Түйінді сөздер: өңделуі қиын кен, флотациялық байыту, байыту коэффициенті, азайту коэффициенті, байыту тиімділігі, Ханкок-Люкина критериі

РЕЗЮМЕ

Исследована проба упорной золотосодержащей руды месторождения «Карьерное», которая подвергалась стадиальному дроблению до класса крупности –0,071+0 мм, с последующим разделением, усреднением в соответствии со стандартной методикой отбора проб (навесок) для технологических исследований и изучения вещественного состава. По данным химического анализа среднее содержание золота в пробе составляет 1,02 г/т. Содержание других элементов и их соединений следующее, %: Fe_2O_3 – 5,3; $Fe_{ок}$ – 2,17; SO_4^{2-} – 0,045; S^{2+} – 0,015; S^{2-} – 0,865; $C_{общ}$ – 1,87; $C_{орг-}$ < 0,1. Минералогическим и электронно-микроскопическим методами анализа установлено, что золото в данной пробе находится в основном в сульфидной форме в виде сростков с пиритом и микрочастиц, вкрапленных в кварц и песчаник. Приведены результаты флотационной обогатимости упорной руды по классической схеме в замкнутом цикле с 3 операциями перечистки. В результате флотационного обогащения исследуемой руды был получен кондиционный флотационнный концентрат с содержанием золота 26,68 г/т (требования по ТУ – более 20 г/т), при этом выход по массе составил 3,48 %, извлечение золота в концентрат перечистки составило 91,0 %. В хвостах флотации содержание золота менее 0,09 г/т, что составляет около 9 % золота. Проведен расчет эффективности процесса флотации по формуле Ханкока-Луйкена, значение коэффициента эффективности (η) составило: η = 87,5%. Такое высокое значение коэффициента эффективности η > 75 %, свидетельствует о том, что процесс флотации весьма эффективен, что подтверждается также и высокими значениями коэффициентов обогащения ($К_{обог.}$ = 26,2) и сокращения (R = 28,7). Учитывая сложный состав флотоконцентрата по вредным примесям (мышьяк, сурьма и органический углерод) и высокое содержание серы сульфидной в виде пирита, процесс дальнейшей его переработки прямым цианированием будет неэффективным. В данном случае, одним из вариантов переработки флотоконцентрата может быть способ предварительного химического окисления сульфидов перед цианированием.

Ключевые слова: упорная руда, флотационное обогащение, коэффициент обогащения, коэффициент сокращения, эффективность обогащения, критерий Ханкока-Луйкена

Received 29.06.2017