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BEHAVIOUR OF SULFUR, ARSENIC AND ORGANIC CARBON IN A GRAVITY CONCENTRATION OF GOLD FROM REFRACTORY ORE

Abstract. The results of assay-gravimetric, chemical, mineralogical analyzes of gold ore are presented. According to the content of sulfide sulfur and the degree of oxidation of sulfur gold-bearing ore is assigned to the poor sulfide type of ore in the primary zone. Gold ore refers to refractory carbonaceous arsenic-containing sulfide ores. The gravity concentration of ore was assessed using a laboratory 3-inch Knelson KC-MD3 centrifugal concentrator. According to the results of the GRG test, the total gold extraction was 39.58% with the total concentrate yield of 3.96%. The extraction of gold in the first stage is lower than in the subsequent stages. This indicates the absence of large gold in the ore. The behavior of sulfur and arsenic during gravity concentration is similar to the behavior of gold. These data confirm that the main amount of gold is associated with arsenopyrite (arsenic pyrite) and pyrite. The behavior of organic carbon during gravity is significantly different. Only 3.39% of organic carbon passes into the gravity concentrate from ore, which reduces the persistence of the concentrate. Most of the organic carbon (96.61%) remains in the tails of gravity. The content of components in the total gravity concentrate was: Au 21.63 g/t, S 6.40%, As 0.82%, C(organic) 0.58%. The extraction of the components in the total concentrate is as follows, %: Au 39.58; S 34.52; As 27.27; C(organic) 3.39.

Key words: refractory ores, preg-robbing, double-refractory ores, gravity concentration method, GRG test, gold ore, carbon-arsenic sulfide ores.

Introduction. The most common reason for the technological persistence of gold-bearing ores is the thin impregnation of gold, which is closely associated with sulfide minerals. Such minerals are most often iron and arsenic sulfides: pyrite and arsenopyrite [1–3]. Direct cyanide leaching of such ore is not effective, the cyanide solution is not accessible to gold even when leaching finely ground (less than 40 μm) raw materials. This type of ore belongs to refractory ores that require preliminary destruction (oxidation) of sulfide minerals and the release of gold from them for its further dissolution [4–7].

Some refractory gold-bearing ores also contain an organic carbonaceous substance that has sorption activity in relation to the gold-cyanide complex (the “preg-robbing” effect), which gives the raw material additional persistence. Therefore, such raw materials are often called double stubborn raw materials. The presence of carbonaceous substances in ores not only complicates the cyanidation process, but also makes it unprofitable due to the low extraction of a valuable component [7–15]. To reduce the sorption activity of the carbonaceous substance that is part of the ore, various methods and techniques are used, which include gravity concentration, flotation, hydrochemical oxidation of chlorine, autoclave and bacterial oxidation, etc. [10–21].

One of the primary methods for processing carbonaceous-arsenic sulfide gold-bearing ores is gravity concentration method. To assess the enrichment of ores by gravity methods, a special GRG test (Gravity recoverable gold test) is most often used in production [22–24]. The methodology for performing the GRG test consists in the stage-by-stage grinding of ore with a gradual reduction in its size and the extraction of gold at each stage as it is released [25–28].

The aim of this work is to study the behavior of sulfur, arsenic and organic carbon during gravity concentration of refractory gold-bearing ore.

Object and method of research. The object of research is the gold-containing ore from one of the deposits of Kazakhstan in the East Kazakhstan region. According to the results of assay-gravimetric analysis, the average gold grade in the ore is 2.29 g/t.

The chemical composition of the ore by main components is shown in table 1.

Table 1 – The results of chemical analysis of the sample

Components	Content, %	Components	Content, %
Copper	0.004	Aluminium oxide	11.52
Nickel	0.01	Arsenic	0.17
Cobalt	0.001	Antimony	undefined
Zinc	0.008	Common carbon	2.59
Lead	0.02	Organic carbon	0.61
Iron	3.77	Carbonate carbon	1.98
Calcium oxide	4.06	Common sulfur	0.80
Magnesium oxide	3.20	Sulphate sulfur	0.04
Sodium oxide	0.72	Sulphide sulfur	0.76
Potassium oxide	2.80	The degree of sulfur oxidation	5.00
Silicon oxide	57.88		
Ore type: *– according to the degree of oxidation of sulfur: primary ore range;* *– by the amount of sulfide sulfur: poor sulfide type.*			

The industrially valuable component in the sample is only gold. The remaining metals, due to their low content, do not represent industrial value. The arsenic content in the sample was 0.17%. Almost all sulfur is represented by a sulfide form. According to the content of sulfide sulfur, the sample is classified as a poor sulfide type. According to the phase composition of sulfur, the sample is assigned to the primary ore range.

Visually and by analysis confirms the presence of carbonaceous shales in the sample. Carbon schists are natural sorbents of gold dissolved in cyanide. Such ores are classified as refractory ores, the extraction of gold from which is difficult. The organic carbon content in the sample was 0.61%.

Complex mineralogical analysis was carried out using x-ray phase, microscopic and optical analyzes. Samples were examined under a microscope in transparent thin sections, and polished sections, artificial briquettes and immersion environment. Gold grains were studied on an electronic microanalyzer of the JEOL JXA – 8230 Electron Probe Microanalyzer brand.

X-ray diffractometric analysis of medium samples was carried out on a DRON-4 diffractometer with Cu - radiation, β-filter. Conditions for recording diffractograms: U = 35 kV; I = 20 mA; survey θ-2θ; detector 2 deg/min.

The identification of the mineral phases according to X-ray diffraction analysis is shown in the diffraction pattern in figure 1.

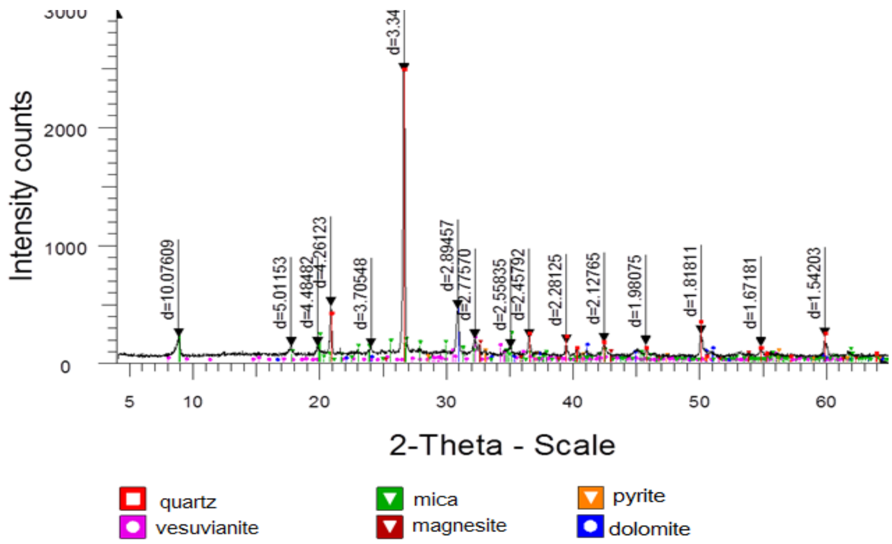

Figure 1 – The diffraction pattern of an average sample

The mineral composition of the average sample, calculated according to x-ray phase analysis using chemical analysis and studying the products under a microscope, the following (%): *ore* – pyrite 1.5–2.0; arsenopyrite 0.4–0.5; iron hydroxides and galenite – significant values; *rock-forming* – quartz 54–55; muscovite 21–22; magnesite 8–10; dolomite 12–13; carbonaceous substance 1; others 1–2.

Methodology for conducting the GRG test. The GRG test was conducted on a 10 kg ore sample at the Knelson concentrator KC-MD3. This test is performed in three stages. At the first stage, the ore weighing 10 kg was crushed to a particle size of 100% of –1.2 mm class and crushed ore was passed through the Knelson concentrator. Next, the tails of the first stage were grinded to a particle size of 80% of –0.3 mm class and passed through the Knelson concentrator. In the third stage, the tails of the second stage were grinded to a particle size of 80% of –0.071 mm class and passed through the Knelson concentrator. During the process, at all stages, samples were taken from the tailings for analysis and preparation of the technological balance. The resulting enrichment products - concentrates and tails were analyzed for gold, sulfur, arsenic and carbon.

The scheme of the GRG test is given in figure 2.

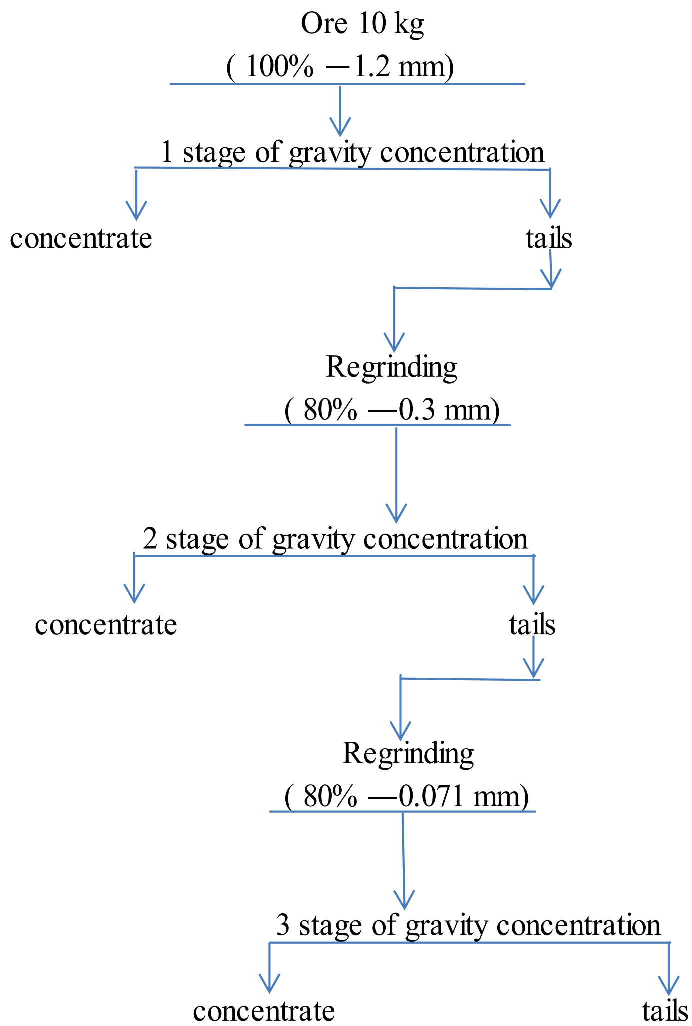

Figure 2 – Scheme of the GRG test

Results and discussion. According to the results of assay, chemical and mineralogical analyzes, only gold is an industrially valuable component.

A GRG test was performed to assess the gravity concentration of gold-containing ore. The results of the GRG test are shown in table 2.

Table 2 – The results of the GRG test

Product	Output		Au content, g/t	Au extraction, %
	g	%		
1 Stage 100 % –1.2 mm				
Concentrate 1	114.8	1.15	23.00	12.33
Tails 1	9885.2	98.85	1.90	87.67
Ore	10000.0	100.00	2.14	100.00
2 Stage 80% –0.3 mm				
Concentrate 2	141.4	1.43	18.87	14.30
Tails 2	9743.8	98.57	1.64	85.70
Tails 1	9885.2	100.00	1.89	100.00
3 Stage 80% –0.071 mm				
Concentrate 3	139.5	1.43	23.30	19.92
Tails 3	9604.4	98.57	1.36	80.08
Tails 2	9743.8	100.00	1.67	100.00
Total				
Concentrate 1	114.80	1.15	23.00	12.21
Concentrate 2	141.36	1.41	18.87	12.34
Concentrate 3	139.46	1.39	23.30	15.03
Concentrate 1+2+3	395.62	3.96	21.63	39.58
Tails 3	9604.38	96.04	1.36	60.42
Ore	10000.00	100.00	2.16	100.00

The total extraction of gold during three-stage enrichment was 39.58 % with a total concentrate yield of 3.96 %. The gold content in the combined concentrate is 21.63 g/t.

According to electron-probe analysis, gold in the ore is present as thin (microns or less) inclusions in pure pyrite and arsenic-containing pyrite. The maximum size of detected gold grains is 4-5 μm. It is possible that smaller gold is part of the crystal lattice of sulfide minerals. The content of the main elements in the composition of native gold, established by electron-probe analysis, varies in the following ranges (%): Au 82–92; Ag 6–10; Fe 1.6–4.9 (figure 3). Electrum has the following composition (%): Au 67.12; Ag 23.70; Fe 9.19 (figure 4).

The GRG test indicators for related components are shown in table 3.

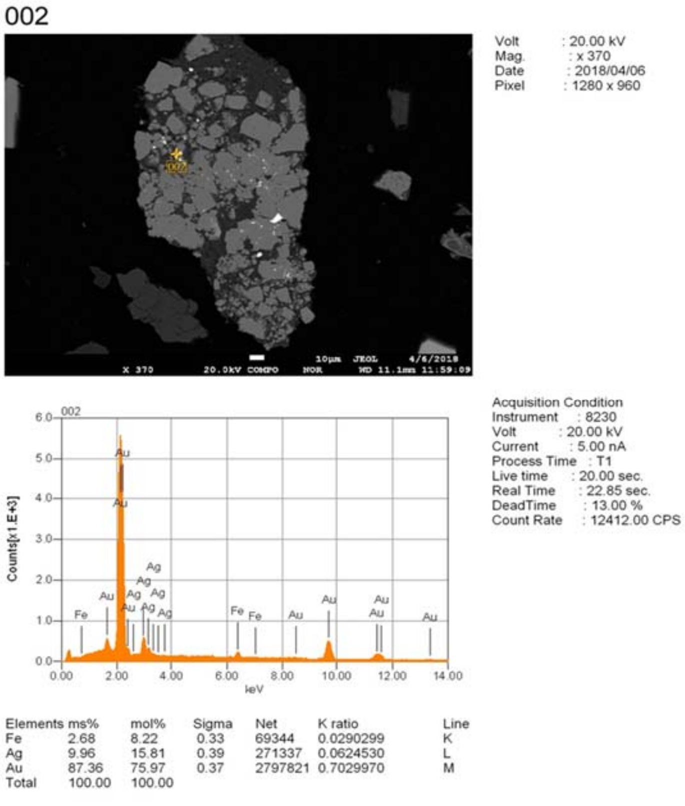

Figure 3 – The high-grade gold in pyrite. The size of gold particles 3–4 μm, EDS mode, x370

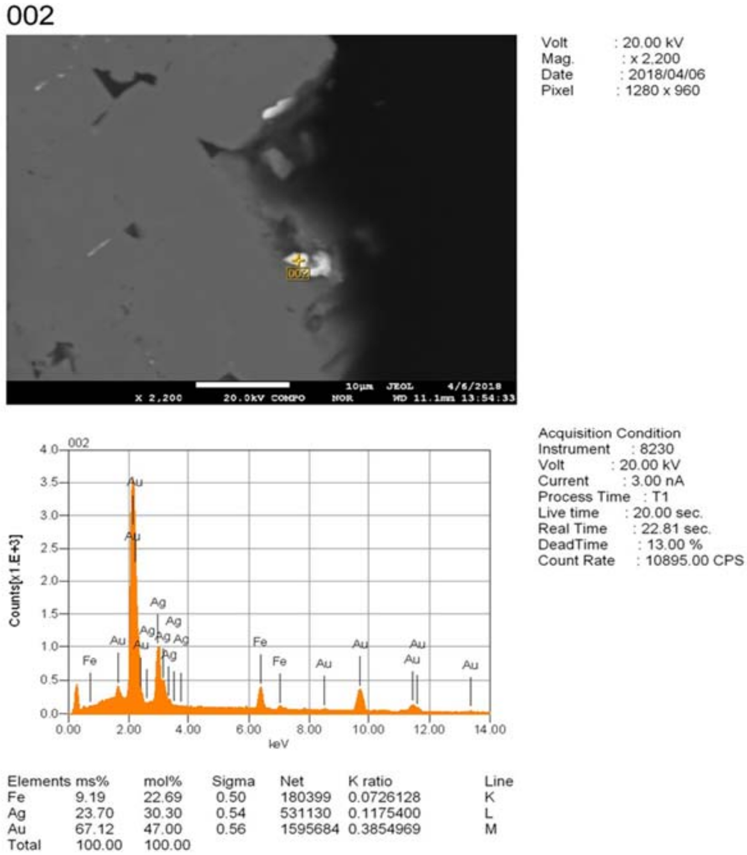

Figure 4 – Electrum (2 grains) in arsenic pyrite. The size of the analyzed grain is about 2 µm, EDS mode, x2200

Table 3 – The GRG test results for sulfur, arsenic and carbon

Product	Output, %	Content,%			Extraction, %		
		S	As	C	S	As	C
1 Stage 100 % –1.2 mm							
Concentrate 1	1.15	8.32	0.94	0.38	12.77	9.03	0.61
Tails 1	98.85	0.66	0.11	0.72	87.23	90.97	99.39
Ore	100.00	0.75	0.12	0.72	100.00	100.00	100.00
2 Stage 80% –0.3 mm							
Concentrate 2	1.43	6.08	0.79	0.77	11.19	10.28	1.83
Tails 2	98.57	0.70	0.10	0.60	88.81	89.72	98.17
Tails 1	100.00	0.78	0.11	0.60	100.00	100.00	100.00
3 Stage 80% –0.071 mm							
Concentrate 3	1.43	5.14	0.75	0.55	12.99	10.79	1.16
Tails 3	98.57	0.50	0.09	0.68	87.01	89.21	98.84
Tails 2	100.00	0.57	0.10	0.68	100.00	100.00	100.00
Total							
Concentrate 1	1.15	8.32	0.94	0.38	13.02	9.08	0.65
Concentrate 2	1.41	6.08	0.79	0.77	11.72	9.40	1.61
Concentrate 3	1.39	5.14	0.75	0.55	9.77	8.80	1.13
Concentrate 1+2+3	3.96	6.40	0.82	0.58	34.52	27.27	3.39
Tails 3	96.04	0.50	0.09	0.68	65.48	72.73	96.61
Ore	100.00	0.73	0.12	0.68	100.00	100.00	100.00

The content of components in the total gravity concentrate was: Au 21.63 g/t, S 6.40%, As 0.82%, C(organic) 0.58%. The extraction of the components in the total concentrate is as follows, %: Au 39.58; S 34.52; As 27.27; C(organic) 3.39.

The extraction of gold in the first stage is lower than in the subsequent stages. This indicates the absence of large gold in the ore. This is more clearly seen in Figure 5, which shows the change in the extraction of gold and related components by stages.

Figure 6 shows the total extraction of gold, sulfur, arsenic, and organic carbon extracted by gravity at various sizes.

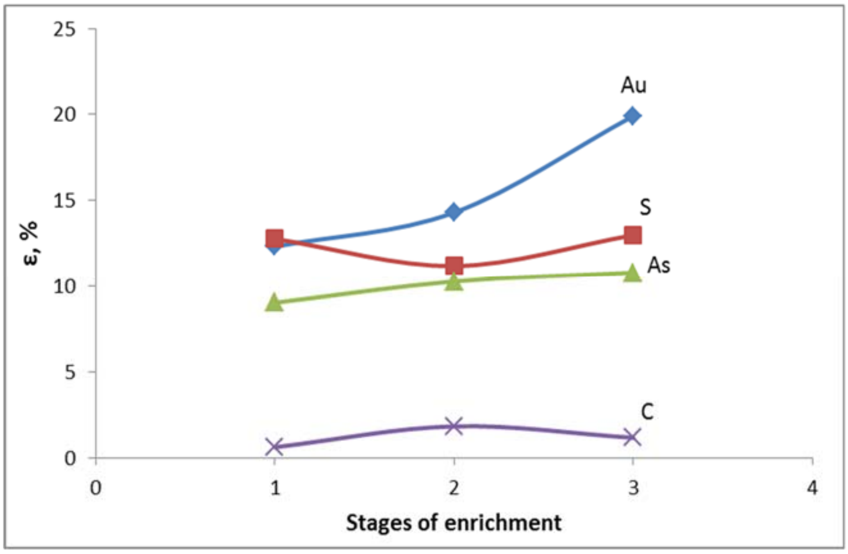

Figure 5 – Extraction of gold, sulfur, arsenic and organic carbon by stages of enrichment (from operation)

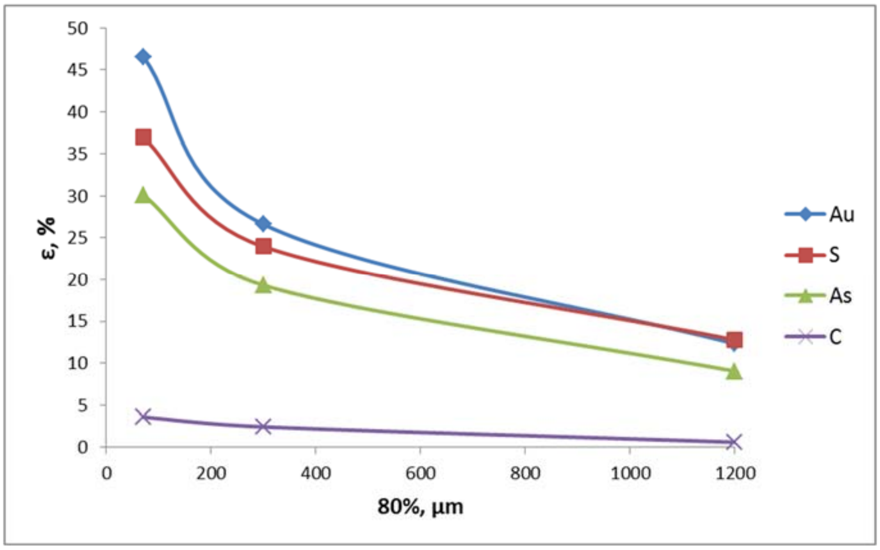

Figure 6 – The total percentage of gold, sulfur, arsenic and organic carbon extracted by gravity at different ore sizes

The nature of the curves for the total extraction of gold and related components (especially sulfur) is identical, which once again confirms the close relationship of gold with these components, which is confirmed by mineralogical analysis (figures 3–4).

First of all, free gold passes into gravity concentrate, if it is present in ore. In the absence of free gold, those sulfide minerals with which gold is associated are transferred to the gravity concentrate, i.e. pyrite and arsenopyrite. The sizes of pyrite grains are mainly from thousandths to 0.05 mm, in some cases up to 0.1 and 0.4–0.5 mm (figure 7), and the sizes of arsenopyrite are 0.02 mm.

The behavior of sulfur and arsenic during gravity concentration is similar to the behavior of gold. These data once again confirm that the main amount of gold is closely associated with arsenopyrite (arsenic pyrite) and pyrite.

The behavior of organic carbon during gravity concentration is significantly different. Only 3–4% of organic carbon passes into the gravity concentrate from ore, which reduces the persistence of the concentrate. The most (96–97%) of organic carbon remains in the tails of gravity.

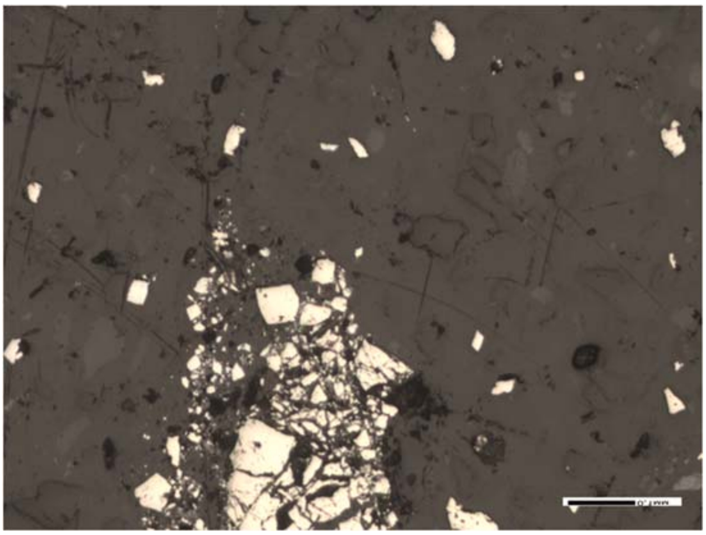

Figure 7 – Gravity concentrate. In the field of view are single crystals of pyrite and its accumulations. Polished artificial briquette, x100

Conclusion. In the gravity concentration of refractory carbonaceous arsenic-containing sulfide ore, gold and sulfide minerals (arsenopyrite, pyrite) with which it is associated are effectively extracted into the gravity concentrate. The extraction of gold and sulfur reached 34–39%, arsenic 27%. The extraction of organic carbon in the gravity concentrate amounted to only about 3.5%. Thus, the gravity concentration method can significantly reduce the content of organic carbon in the enriched product and, accordingly, reduce the persistence of the obtained product during further processing.

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КҮРДЕЛІ БАЙЫТЫЛАТЫН КЕННЕН АЛТЫНДЫ ГРАВИТАЦИЯЛЫҚ БАЙЫТУ КЕЗІНДЕГІ КҮКІРТ, КҮШАЛА ЖӘНЕ ОРГАНИКАЛЫҚ КӨМІРТЕКТІҢ ӘСЕРІ

Аннотация. Күрделі байытылатын алтынқұрамды технологиялық кеннің кеңірек таралу себебі – алтынның сульфидті минералдармен тығыз байланыстылығында. Мұндай минералдар көбінесе темір мен күшала сульфидтері: пирит және арсенопирит.

Күрделі байытылатын алтынқұрамынды кенде алтын-цианидті кешенге қатысты сорбциялық белсенді органикалық көміртекті зат бар («preg-robbing» әсері), бұл шикізатқа қосымша беріктік сипат береді. Сондықтан мұндай шикізат көбінесе екі есе берік шикізат деп аталады. Кенде көміртекті заттардың болуы цианирлеу үдерісін күрделендіріп қана қоймай, бағалы компоненттің төмен бөліну салдарынан оны тиімсіз етеді. Кен құрамына кіретін көміртекті заттардың сорбциялық белсенділігін төмендету үшін гравитация, флотация, хлормен гидрохимиялық тотықтыру, автоклавтық және бактериялық тотықтыру және т.б. қамтитын әртүрлі әдістер мен технологиялық тәсілдер қолданылады. Көміртекті-күшала сульфидті алтынқұрамды кен өңдеудің бастапқы әдістерінің бірі гравитациялық байыту болып саналады. Гравитациялық әдістермен кеннің байытылу үдерісін бағалау үшін өндірісте жиі арнайы GRG тест (Gravity recoverable gold test) қолданылады.

Жұмыстың мақсаты – күрделі байытылатын алтынқұрамды кенді гравитациялық байыту кезіндегі күкірт, күшала және органикалық көміртектің әсерін зерттеу.

Зерттеу нысаны – Шығыс Қазақстан облысындағы алтынқұрамынды кен. Сынамалы-гравиметрлік талдау нәтижелері бойынша кендегі алтынның орташа құрамы тоннасына 2,29 г құрайды. Сынамадағы күшала мөлшері 0,17 % құрады. Кенде барлық күкірт сульфид түрінде ұсынылған. Сульфидті күкірттің құрамы бойынша сынама аз сульфидті типке жатқызылған. Күкірттің фазалық құрамы бойынша сынама кеннің сульфидті типіне жатады.

Визуалды түрде де және талдау нәтижесінде де сынамада көмірлі сланцтердің болатыны расталады. Көмірлі сланцтер цианидте еріген алтынның табиғи сорбенттері болып саналады. Мұндай кен күрделі байытылатын кенге жатады, олардан алтынды алу қиын. Сынамадағы органикалық көміртек мөлшері 0,61 % құрады. Зертеуге берілген алтын құрамынды кен күрделі байытылатын көміртекті-күшала типтес сульфидті кенге жатады.

Кеннің гравитациялық байыту жұмысын бағалау үшін Нельсон KC-MD3 зертханалық 3 дюймдік центрден тепкіш концентраторы қолданылды. GRG сынағының нәтижелері бойынша алтынның жалпы бөлінуі 39,58 %, концентраттың жалпы шығымы 3,96 % құрады. Бірінші сатыдағы алтынның жалпы бөлінуі кейінгі сатыларға қарағанда азырақ. Бұл кенде ірі алтынның жоқтығын көрсетеді. Гравитациялық байыту кезінде күкірт және күшаланың бөлінуі алтынның бөлінуіне ұқсас. Бұл деректер алтынның арсенопиритпен (күшала пиритімен) және пиритпен байланысты екенін растайды. Гравитация кезіндегі органикалық көміртектің бөлінуі айтарлықтай ерекшеленеді. Гравитациялық концентратқа кеннен органикалық көміртектің небәрі 3,39 % өтеді, бұл концентрат беріктігін төмендетеді. Органикалық көміртектің көп бөлігі (96,61 %) гравитация қалдықтарында қалады. Жиынтық гравитациялық концентраттағы компоненттердің құрамы Au – 21,63 г/т, S – 6,40 %, As – 0,82 %, C (органикалық) – 0,58 % құрады. Компоненттерді жиынтық концентратқа бөлінуі, %: Au – 39,58; S – 34,52; As – 27,27; C (органикалық) – 3,39. Осылайша, гравитациялық байыту байытылған өнімдегі органикалық көміртек мөлшерін айтарлықтай азайтуға және одан әрі өңдеу кезінде алынған өнімнің беріктігін төмендетуге мүмкіндік береді.

Түйін сөздер: күрделі байытылатын кен, preg-robbing, күрделі байытылатын қос кен, гравитациялық байыту әдістері, GRG тест, алтынқұрамды кен, көміртекті-күшала сульфидті кен.

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ПОВЕДЕНИЕ СЕРЫ, МЫШЬЯКА И ОРГАНИЧЕСКОГО УГЛЕРОДА ПРИ ГРАВИТАЦИОННОМ ОБОГАЩЕНИИ ЗОЛОТА ИЗ УПОРНОЙ РУДЫ

Аннотация. Наиболее распространенной причиной технологической упорности золотосодержащих руд является тонкая вкрапленность золота, тесно ассоциированного с сульфидными минералами. Такими минералами чаще всего являются сульфиды железа и мышьяка: пирит и арсенопирит.

В некоторых упорных золотосодержащих рудах содержится также органическое углистое вещество, обладающее сорбционной активностью по отношению к золотоцианидному комплексу (эффект «preg-robbing»), что придает сырью дополнительную упорность. Поэтому такое сырье часто называют сырьем двойной упорности. Наличие в рудах углеродистых веществ не только затрудняет процесс цианирования, но и делает его нерентабельным вследствие низкого извлечения ценного компонента. Для снижения сорбционной активности углеродистого вещества, входящего в состав руды, применяют различные методы и технологические приемы, которые включают гравитацию, флотацию, гидрохимическое окисление хлором, автоклавное и бактериальное окисление и т.д. Одним из первичных методов переработки углисто-мышьяковистых сульфидных золотосодержащих руд является гравитационное обогащение. Для оценки обогатимости руд гравитационными методами чаще всего в производстве используют специальный GRG тест (Gravity recoverable gold test).

Целью работы является изучение поведения серы, мышьяка и органического углерода при гравитационном обогащении упорной золотосодержащей руды.

Объектом исследований является золотосодержащая руда одного из месторождения Казахстана в Восточно-Казахстанской области. По результатам пробирно-гравиметрического анализа среднее содержание золота в руде составляет 2,29 г/т. Промышленно ценным компонентом в пробе является только золото. Содержание мышьяка в пробе составило 0,17 %. Практически вся сера представлена сульфидной формой. По содержанию сульфидной серы проба отнесена к убогосульфидному типу. По фазовому составу серы проба отнесена к первичному типу руды.

Визуально и анализом подтверждается наличие в пробе углистых сланцев. Углистые сланцы являются природными сорбентами растворенного в цианиде золота. Такие руды относят к упорным рудам, извлечение золота из которых затруднено. Содержание органического углерода в пробе составило 0,61 %. Золотосодержащая руда относится к упорным углистым мышьяксодержащим сульфидным рудам.

Проведена оценка гравитационной обогатимости руды на лабораторном 3-х дюймовом центробежном концентраторе Нельсона KC-MD3. По результатам GRG теста суммарное извлечение золота составило 39,58 % при выходе суммарного концентрата 3,96 %. Извлечение золота на первой стадии более низкое, чем на последующих стадиях. Это указывает на отсутствие в руде крупного золота. Поведение серы и мышьяка, при гравитационном обогащении аналогично поведению золота. Эти данные подтверждают, что основное количество золота ассоциировано с арсенопиритом (мышьяковистым пиритом) и пиритом. Поведение органического углерода при гравитации существенно отличается. В гравитационный концентрат из руды переходит всего 3,39 % органического углерода, что снижает упорность концентрата. Большая часть (96,61 %) органического углерода остается в хвостах гравитации. Содержание компонентов в суммарном гравитационном концентрате составило: Au – 21,63 г/т, S – 6,40 %, As – 0,82 %, C(органическая) – 0,58 %. Извлечение компонентов в суммарный концентрат следующее, %: Au – 39,58; S – 34,52; As – 27,27; C(органическая) – 3,39. Таким образом, гравитационное обогащение позволяет существенно снизить содержание органического углерода в обогащенном продукте и, соответственно, снизить упорность полученного продукта при дальнейшей переработке.

Ключевые слова: упорные руды, preg-robbing, руды двойной упорности, гравитационные методы обогащения, GRG тест, золотосодержащая руда, углисто-мышьяковистые сульфидные руды.

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