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Increase in the Free Finely-Dispersed Gold Recovery in the Flotation Cycle

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ABSTRACT

This article presents the results of a comparative study for the increase in the free finely dispersed gold recovery from the gold-bearing ore produced in a deposit in Kazakhstan. The following minerals were identified in the sample under X-ray phase analysis: chalcopyrite and pyrite, as well as in a finely disseminated state in silicate minerals. Gold in the ore is present mainly (40.09%) in the free form under the results of phase analysis. Flotation tests of ore beneficiation were performed in FML-1 and FML-3 flotation machines with chamber volumes of 1.0 and 3.0 liters. A flotation combined concentrate with a gold content of 15.3 g/t was obtained (concentrate yield 9.45%), with gold recovery into concentrate 82.79% in the optimal mode: the grind of 90% in the class -0.071 mm; consumption of reagents: C7 foaming agent – 30 and 60 g/t, sodium butyl xanthate – 60 and 120 g/t; the time of the main flotation – 10 minutes, the control flotation – 7 minutes, at pH = 9. Flotation tailings contained 0.33 g/t of gold. The recovery showed a fairly high 84.42% (yield of the total concentrate 20.93%) with the gold content of 7.1 g/t with the use of a sulfidizing agent (Na_2S) and additional dispersion of the pulp at pH = 9.0. A gold-bearing concentrate was obtained containing 4.0 g/t Au at a fineness of -0.05 mm and 6.8 g/t Au at a fineness of +0.05 mm. The beneficiation of the pulp with a fineness of +0.05 mm gave the recovery into the final concentrate equal to 89.94%.

Keywords: hydrometallurgy, ore, recovery, free finely dispersed gold, flotation, sulfidizer, pulp dispersion.

INTRODUCTION

Many minerals with a metallic lustre fall into the category hydrophobic ones and naturally interact well with oily and fatty substances. They include a number of sulfide minerals capable to contain precious metals, such as galena (lead sulfide), chalcopyrite (copper) and sphalerite (zinc sulfide). In other words, their surface, in the presence of water and oil, shows a noticeable susceptibility to the latter. On the other hand, many empty or waste materials with a glassy lustre, such as quartz or calcite, easily interact with water. Miners were well aware of these differences already at the beginning of the 20th century, [Bocharov et al., 2013; Koizhanova et al., 2020; Kenzhaliyev et al., 2019]. They took them into account and used them when they developed a beneficiation method supposed to effectively separate precious metal minerals from the rest ones within the same deposit. Finally, it was called froth flotation [Adams et al., 2016; Bhattacharyya et al., 2014; Kondratiev 2010].

The main idea behind the froth flotation method is well known and familiar to any prospector who has ever had the opportunity to observe how small particles of gold are collected on the water surface (gold is partially hydrophobic) [Matveeva et al., 2008; Ignatkina et al., 2009].

They must be sufficiently crushed for effective separation of minerals. It is almost impossible to extract tiny particles of sulfides on the fat table. During the flotation process hydrophobic particles attach to air bubbles (and vice versa), and rise with them to the foam surface. The surface of minerals that interact better with water (for example, “glassy” calcite, quartz and other silicates) is completely wetted, preventing adhesion to the bubbles which simply move past in this case, and the empty minerals themselves settle to the bottom.

Gold-bearing ores are characterized by great diversity, both in material composition and fineness. With the depletion of rich deposits and the need to involve in the processing of poor finely disseminated (refractory) ores, the opening of which requires very fine grinding, the problem of flotation recovery of fine-dispersed gold becomes of particular importance [Koizhanova et al., 2022; Ultarakova et al., 2022; Wikedzi et al., 2018].

Despite significant studies intended to improve the efficiency of gold recovery, the flotation recovery of fine-dispersed gold associated with sulfides and quartz does not exceed 60–80%, and in some cases 30–40%. Thus, increase in the recovery of precious metals from mineral raw materials is an urgent task.

Studies show that it is possible to increase the mineral resource base of gold with the help of poor, refractory and technogenic raw materials that can be achieved as a result of increase in the efficiency of processing technology and the completeness of a valuable component recovery. A significant part of noble metals in sulfide ores is concentrated in a finely dispersed phase. Free and sulfide-bound gold is efficiently recovered by flotation [Yessengaziyev et al., 2020].

MATERIAL AND METHODS

Detailed elemental composition of the original ore sample from one of the fields in Kazakhstan, presented in Table 1, was determined by fluorescent analysis, enabling to capture the spectra of elements from oxygen to uranium.

A mineralogical analysis was performed to identify potentially gold-bearing sulfide minerals. Discontinuous thin veins of chalcopyrite occur among sulfide minerals (Figure 1). Grains are found both free and in the intergrowth of non-metallic mass. The grain size is from 0.01 to 0.6 mm. Pyrite is also found as inclusions in the non-metallic mass, has a less yellow tint than chalcopyrite. There are accessory minerals, i.e. ilmenite. There are single grains of covellite that develops in the margins of chalcopyrite. Besides, there are inclusions of magnetite intergrown with pyrite.

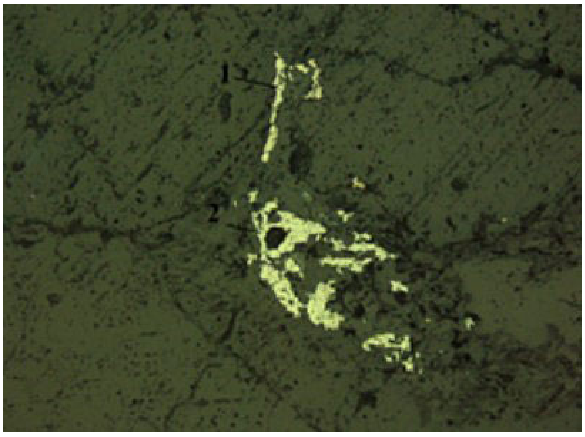

Figure 1. Grains of chalcopyrite and pyrite in an intergrowth of non-metallic mass. Magnification 100

Table 1. Results of X-ray fluorescence analysis of the ore sample from the Vasilkovskoye deposit

Element	Content, %	Element	Content, %	Element	Content, %	Element	Content, %
O	47.51	P	0.061	Ti	0.261	Ga	0.002
Na	1.192	S	0.236	Mn	0.033	As	0.783
mg	1.394	Cl	0.015	Fe	2.62	Rb	0.013
Al	6.334	To	1.608	Cu	0.02	Sr	0.015
Si	23.871	Ca	2.552	Zn	0.01	Zr	0.007

Table 2. Results of rational (phase) gold analysis

Forms of gold and the nature of its relationship with ore components	Au content, g\t	Au distribution, %
Free gold with clean surface at 60% grade minus 0.071 mm	0.40	18.43
Free gold with clean surface at 90% grade minus 0.071 mm	0.47	21.66
Whole gold free with clean surface:	0.33	15.21
Gold in intergrowths (cyanidated)	0.20	9.22
Gold in aqua regia-insoluble minerals and quartz	0.77	35.48

As can be seen in Figures 1 and 2, chalcopyrite, pyrite, in addition to the main structural elements – copper, iron and sulfur, also contains covellite, ilmenite and magnetite.

A mineralogical analysis of an ore sample with an initial fineness class of -0.05 mm and +0.05 mm was performed to find the forms of gold. Below, in Figure 3, gold particles in a free state are found. They are covered with oxidation films, possibly of goethite-limonite composition, which, in turn, gives them a reddish tint.

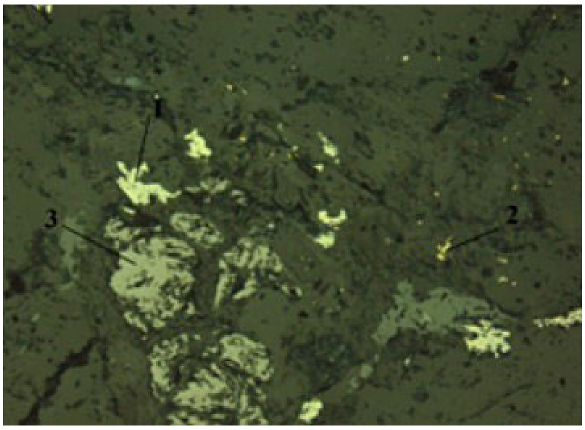

Figure 2. Ilmenite fully or partially replaced in the non-metallic mass, pyrite and chalcopyrite, both free and in the intergrowth of the non-metallic mass

RESULTS AND DISCUSSION

The flotation process is performed in a stirred aqueous mineral suspension (flotation pulp), into which air bubbles are introduced by one or another method. At the same time, mineral particles that are poorly wetted by water (hydrophobic), when they are in contact with air bubbles, stick to them and float to the surface of the pulp, forming a layer of mineralized foam released by gravity or forcibly with the help of special rakes into a separate product (flotation foam product). Other minerals that are well wetted by water (hydrophilic) remain in the bulk of the flotation pulp, forming a flotation tail. Usually, a useful mineral is transferred into the foam product and is called a concentrate, and the flotation tail where the waste rock is concentrated, is called tailings (wastes).

The development of optimal flotation beneficiation modes for the test sample was performed

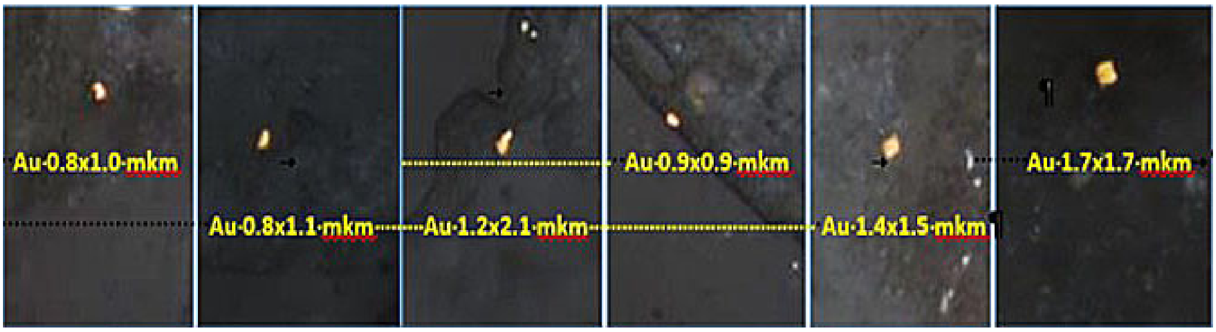

Figure 3. Free gold particles covered with oxidation films

Table 3. Results of flotation of raw materials with particle sizes of ± 0.05 mm and concentrates from one of the deposits in Kazakhstan in the main mode

Name of products	Yield		Content	Recovery	Note
	g	%	Au, g/t	Au, %	
Main concentrate	220.0	22.0	4.9	44.36	minus 0.05 mm
Control concentrate	180.0	18.0	2.84	20.87	
United concentrate	400.0	40.0	4.0	65.22	
Tails	600.0	60.0	1.42	34.78	
Initial	1000.0	100.0	2.45	100.0	
Main concentrate	141.1	14.11	8.2	85.29	plus 0.05 mm
Control concentrate	38.3	3.83	1.64	4.65	
United concentrate	179.4	17.94	6.8	89.94	
Tails	820.6	82.06	0.17	10.06	
Initial	1000.0	100.0	1.35	100.0	

in an open cycle. Sodium butyl xanthate that is a fairly strong comprehensive collector was used as a collector. C7 that is widespread was used as a blowing agent. 5 variants of beneficiation modes were performed at different pulp media in the course of flotation experiments: pH 8.0; 9.0; 10.0 and with the use of a sulfidizer (Na_2S) and additional dispersion of the pulp.

The results of Table 3 show that a gold-bearing concentrate was obtained containing 4.0 g/t and 6.8 g/t of gold with the division of the pulp into size classes of minus 0.05 mm and plus 0.05 mm with the main reagent mode. Thus, the beneficiation of the initial sample of the pulp with a size class of -0.05 mm and a gold content of 2.45 g/t makes it possible to extract only 65.22% into the final concentrate. Beneficiation of the pulp with a fineness of +0.05 mm with a content of 1.35 g/t gives a recovery into the final concentrate equal to 89.94%.

CONCLUSIONS

The material composition of the original gold-bearing ore of one of the deposits in Kazakhstan at the stage of coarse, medium and fine crushing was studied. Assay, chemical, X-ray fluorescence, X-ray phase, rational analysis for gold and mineralogical study were performed.

Only gold in the ore has commercial value, its content is 1.75 g/t according to assay data. The ore belongs to the silicate type according to its main composition but there are also phenocrysts of sulfide minerals like pyrite and arsenopyrite. Mineralogical study shows that gold is in hard to extract form with quartz.

The proportion of free gold is 18.43% at 60%, and 21.66% at 90% -0.071 mm with a class size of -0.071 mm according to the phase analysis. The gold fraction in aggregates (cyanide-bearing) is 0.77%. Gold is found as fine grains in sulfides (chalcopyrite and pyrite), as well as in a thinly disseminated state in silicate minerals.

The reagent mode of ore flotation of Vasilkovskoye deposit with the use of main reagents has been worked out. The optimum regrinding regimen of initial ore has been determined. Consumption of main reagents has been chosen. Butyl xanthate that is a strong comprehensive collector was used as collector. C7 that is widespread was used as a foaming agent. 5 variants of beneficiation regimes with different pulp media were performed in the course of flotation experiments: pH 8.0; 9.0; 10.0, and also with application of sulfidizer (Na_2S) and additional pulp dispersion. As a result, it was noted that it is advisable to preliminarily increase the pH of the initial pulp from 8.0 to 9.0 to increase the efficiency of flotation beneficiation.

It was found that there was a significant fine gold amount that usually includes grains of size from fractions of a micrometer to 10 microns. Micro-nanometer gold may be present in sulfides, carbonates, silicates, oxides and hydroxides

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