P. K. FEDOTOV, A. E. SENCHENKO, K. V. FEDOTOV, A. E. BURDONOV

ISSN 0543-5846
METABK 60(1-2) 85-88 (2021)
UDC – UDK 669.052.21:669.011:66.082:66.067:661.185=111

HYDROMETALLURGICAL PROCESSING OF GOLD-CONTAINING ORE AND ITS WASHED PRODUCTS

Received – Primljeno: 2020-08-29
Accepted – Prihvaćeno: 2020-10-30
Preliminary Note – Prethodno priopćenje

This article presents the results of hydrometallurgical studies of gold-bearing ore. The experiments were carried out on 2 parallel weighed portions with the analysis of products by assay (cake) and atomic absorption (solution) analyzes of gold. To determine the technological properties, tests were carried out on the direct and sorption cyanidation of ore samples using different material sizes, the concentration of the complexing agent in the solution and the preliminary treatment of the pulp with lime. The study of the sorption activity of the ore, as well as the dynamics of gold dissolution was carried out.

Keywords: ore, gold, hydrometallurgy, leaching, concentrate, flotation tailings

INTRODUCTION

On the basis of analytical studies, it was established that in the mining and metallurgical industry, there is a regular increase in gold production by at least 1–2 %. In recent years, a huge amount of work were done in terms of the implementation of a number of projects and research [1-2], which will provide a breakthrough in gold mining in the coming years. To maintain development trends in this area, it is necessary to continue scientific research, and the results obtained to be implemented at industrial enterprises [3]. In this connection, this work is devoted to the hydrometallurgical processing of gold-bearing ore, as well as the products of its enrichment in order to use the results obtained and the developed methodology in the national economy and in scientific research.

Within the framework of the project, a technological sample of an ore of a gold ore deposit weighing 500 kg, which characterizes the gold-quartz type of ore, was investigated. The granulometric composition of the ore with a particle size of - 2 + 0 mm, prepared for tests, is presented in Table 1.

Its content in size classes ranges from 2,2 g / t (- 0,045 + 0 mm) to 7,2 g / t (- 0,2 + 0,1 mm). This distribution pattern is a sign of the presence of large and medium sized gold particles in the crushed ore in free form and in rich intergrowths.

It was noted that the rocks of the deposit are represented by gray and dark gray thin-banded shales of substantially quartz-mica composition, often with coarse-grained quartz veinlets and proper vein light gray and dark gray cataclastic quartz, partially with segregations of ankerite and fine grained ore minerals

A full semi-quantitative mineralogical analysis was carried out on material with a particle size of 2 mm. The main rock-forming minerals of the original ore are: quartz (38,9 %), quartz-sericite aggregates – 35,8 %; carbonates (Fe calcite, ankerite) – 0,6 %; chlorite - signs. Slimes are represented by mica-quartz mass – 21,3 %. Ore minerals (sulfides) are present in the following quantities: pyrite – 2,6 %; arsenopyrite – 0,7 %, sphalerite - signs, chalcopyrite and fahlore - rare signs. In terms of sulfide content, the ore of the deposit is classified as moderate sulfide, in terms of the oxidation state - to sulfide.

Cyanidation of ores of various sizes

To study the effect of material size on gold recovery, leaching tests of the original ore with a size of 80 %, 90 % and 95 % - 0,074 mm, 95 % - 0,045 mm and 95 % - 0,020 mm were performed.

During the tests, the kinetics of cyanidation was studied, the concentration of NaCN and the pH of the pulp were monitored. To check the presence of sorption activity in the studied material with respect to gold, all tests were performed both in direct and in sorption modes of cyanidation. Studies on ore leaching were carried out with the following parameters: cyanide concentration – 0,2 %, cyanidation duration – 24 h, pH – 10,5, pulp density during cyanidation – 40 % solids, coal loading during sorption cyanidation – 10 % of the volume of the liquid phase. Figure 1 shows the dynamics of the transition of gold into solution during direct cyanidation.

It was established that the original ore is resistant to processing by hydrometallurgical methods. The recovery of gold during sorption leaching at a grain size of 80

P. K. Fedotov (e-mail: fedotovpavel@yandex.ru) Department of Mineral Processing, Irkutsk National Research Technical University, Russia, A.E. Senchenko (e-mail: senchenko@tomsgroup.ru) TOMS Institute, Russia, K. V Fedotov. (e-mail: fedotov@istu.edu) Department of Mineral Processing, Irkutsk National Research Technical University, Russia,
A. E. Burdonov (e-mail: slimbul@inbox.ru) Department of Mineral Processing, Irkutsk National Research Technical University, Russia.

Table 1 **Granulometric characteristics of crushed ore (-2 mm) with distribution of gold, silver, iron and sulfur by size classes**

Product	Output / %	Σ γ"-" / %	Au / content / g/t	Au / distribution / %	Ag / content / g/t	Ag / distribution / %	Fe / content / g/t	Fe / distribution / %	S / content / g/t	S / distribution / %
- 2 + 1	35,98	100,00	4,80	39,08	2,00	35,98	3,43	31,73	2,18	32,70
- 1 + 0,5	20,08	64,02	4,20	19,09	2,00	20,08	3,57	18,43	2,09	17,50
- 0,5 + 0,315	9,21	43,93	3,00	6,25	2,00	9,21	3,36	7,95	1,81	6,95
- 0,315 + 0,2	7,01	34,73	5,80	9,20	2,00	7,01	3,99	7,19	2,36	6,89
- 0,2 + 0,1	7,43	27,72	7,20	3,29	2,00	3,03	7,55	5,89	6,14	7,76
- 0,1 + 0,071	3,03	20,29	4,80	3,91	2,00	3,03	6,85	5,34	4,76	6,02
-0,071 +0,045	3,03	17,26	5,70	7,08	2,00	14,23	3,64	13,31	1,85	10,97
-0,045+0	14,23	14,23	2,20	100,00	2,00	100,00	3,89	100,00	2,40	100,00
Total	100,00	-	4,42							

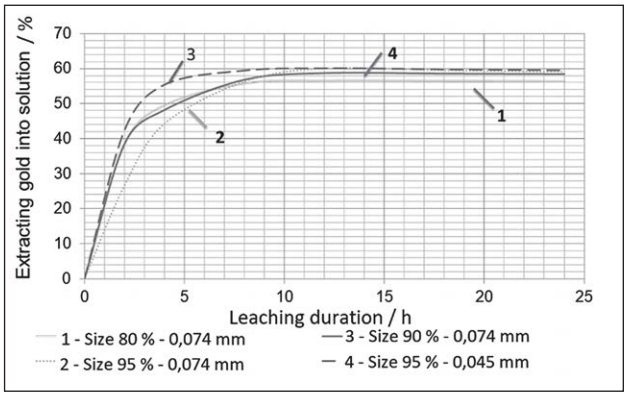

Figure 1 Leaching dynamics of the original ore

Table 2 **Leaching results of original ore with lime pretreatment**

Material size / mm	Gold content / g / t		Gold recover / %	Reagent consumption kg / t ore		
				NaCN		*CaO*
	In source	In cake		full	taking into account the residue	
95 % -0,074	4,26	1,67	60,80	3,0	1,67	3,84
		1,68	60,56	3,0	1,69	3,84
95 % -0,045		1,68	60,56	3,0	1,77	3,84
		1,68	60,56	3,0	1,82	3,84

% - 0,074 mm is on average 57,52 % (the gold content in leaching cakes is 1,80 – 1,82 g / t).

Reducing the size of the material from 80 % -0,074 mm to 95 % - 0,045 mm does not lead to a significant increase in gold recovery. Further reduction of the size up to 95 % - 0,020 mm allows increasing gold recovery up to 79,23 %.

The nature of the curves shows that the required duration of the leaching process should be at least 10 - 12 hours of agitation.

Comparative analysis of the results of direct and sorption cyanidation indicates that the ore has sorption activity with respect to gold.

The stubbornness of the original ore of the deposit is associated, first of all, with the presence of predominantly fine gold in the material, which is difficult to open during grinding.

Cyanidation of ore with lime pretreatment of pulp

In the process of grinding the material, side processes occur associated with the chemical activation of the surface of mineral particles (mainly sulfides), which entails an increase in the sorption activity of the ore, an increase in its cyanide and depressing properties [4].

To reduce the negative effect of these factors, tests were performed on sorption leaching of ore at a size of 95 % - 0,074 mm and 95 % - 0,045 mm with preliminary treatment of the pulp with lime. The treatment was carried out for 2 hours with a lime concentration in the solution of 0,02 %.

During the tests, the concentration of cyanide in the solution was monitored, the pH of the pulp was maintained at a given level by adding lime. The test results are presented in Table 2.

It was found that the pretreatment of the pulp with lime makes it possible to slightly increase the gold recovery and reduce the consumption of cyanide for leaching. Due to the fact that when the size is reduced to 95 % - 0,045 mm, there is no increase in gold recovery from the ore, further studies were carried out on the material size 95 % - 0,074 mm. Cyanide consumption in this case was 1,68 kg / t (taking into account the remainder of the reagent), lime – 3,84 kg / t.

Cyanidation of ore at different concentration of complexing agent

To study the effect of the concentration of the complexing agent on gold recovery, leaching tests of the original ore with sodium cyanide concentration in the solution of 0,15 % and 0,1 % were performed.

The tests were carried out in sorption mode on a material size of 95 % - 0,074 mm with preliminary treatment of the pulp with lime at a density of 40 % solid. The leaching time was 24 hours. Loading coal into the process – 10 % of the volume of the liquid phase. During the tests, the concentration of NaCN was monitored, the pH of the pulp was maintained at 10,5 by adding lime. A decrease in the concentration of sodium cyanide in the solution from 0,2 % to 0,1 % does not lead to a decrease in the extraction of gold into the solution,

therefore, it is recommended to carry out the process of leaching the original ore at a concentration of sodium cyanide in the solution of 0,1 %. Gold recovery is 60,56 %, cyanide consumption is 1,50 kg / t (full), lime consumption is 3,84 kg / t.

HYDROMETALLURGICAL RESEARCH OF BENEFICIATION PRODUCTS

Within the framework of this project, studies were carried out on gravity and flotation concentration of the studied ore. As a result of the research, the following products were, obtained: gravity tailings, gravity and flotation concentrates. This paper presents the results of hydrometallurgical studies of the obtained concentration products.

Intensive cyanidation of gravity concentrate

Intensive cyanidation of the gravity concentrate was carried out in the following mode: cyanide concentration – 2 %; NaOH concentration – 0,2 %; accelerator reagent consumption (LeachAid) – 0,2 kg / t; temperature - 60 °C; duration of cyanidation - 24 hours; material size (initial) – 31,8 % - 0,074 mm; pulp density at cyanidation 25 % solids.

During the test, the concentration of NaCN and NaOH was monitored. The results of cyanidation are presented in Table 3. Figure 2 shows the dynamics of the cyanidation of the concentrate.

The results of the test on intensive cyanidation showed the high efficiency of this process in relation to the gravity concentrate of the deposit (the extraction of gold into solution was 93,9 %). The required leaching time is 10 hours, the cyanide consumption is 55,2 kg / t (including the reagent residue). Similar results were obtained by the authors in [5].

The consumption of sodium cyanide for intensive leaching, taking into account the use of a partial turnover of the solution and losses of the reagent during the actual cyanidation, electrolysis, as well as taking into account the removal of excess solution from the intensive cyanidation cycle, will be 57,8 kg / t.

Table 3 **Intensive cyanidation of gravity concentrate**

Au / content / g/t		Extracting Au in Solution / %	Reagent consumption kg / ton of product		
			NaCN	NaOH taking into account the residue	
initial	In cake		full		
538,19	33,0	93,87	60,0	55,20	6,0

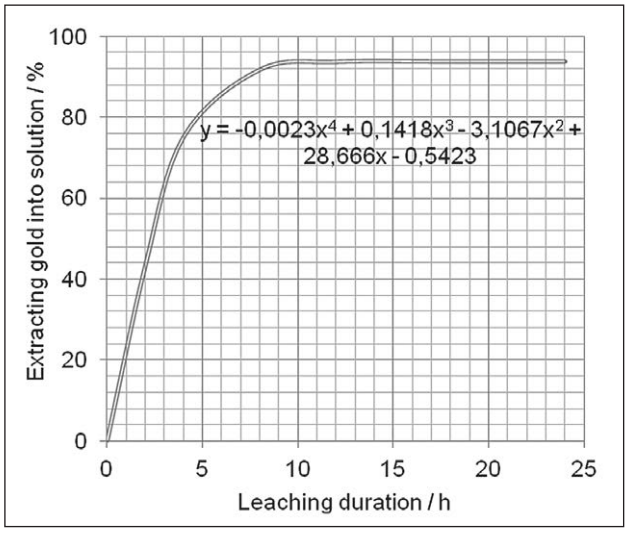

Figure 2 Dynamics of intensive cyanidation of gravity concentrate

Gravity tails cyanidation research

To study the behavior of gravity tailings in the process of hydrometallurgical processing, tests were performed on their leaching at a size of 95 % -0,074 mm with a cyanide concentration in the solution of 0,2 – 0,05 %. This size was selected based on the results of studies of the original ore.

Leaching of the tailings was carried out in a sorption mode at a pulp density of 40 % solid for 24 hours. The loading of coal into the process was taken equal to 10 % of the volume of the liquid phase. During the tests, the concentration of NaCN was monitored, the pH of the pulp was maintained at 10,5 by adding lime. The test results are presented in Table 4.

The conducted research was established the persistence of gravity tailings in relation to the leaching process. The recovery of gold in the cyanide concentration range of 0,05 – 0,2 % remains constant and averages 32,46 %. The total consumption of cyanide for leaching is 0,75 kg /t, lime – 3,3 kg / t.

Hydrometallurgical studies of flotation concentrate

To study the technological properties of the flotation concentrate, tests on its leaching in the sorption mode were performed at the initial size (96,5 % - 0,074 mm) and after regrinding to a size of 95 % -0,.02 mm. During

Table 4 **Leaching of gravity tailings at different concentration of complexing agent**

NaCN concentration / %	Gold content g/t		Gold recovery / %	Reagent consumption kg / ton of product		
				NaCN		CaO
	In source	In cake		full	taking into account the residue	
0,20	2,28	1,53	32,89	3,0	1,18	3,25
		1,53	32,89	3,0	1,16	3,25
0,10		1,54	32,46	1,50	0,64	3,25
		1,55	32,02	1,50	0,69	3,25
0,05		1,53	32,89	0,75	0,59	3,25
		1,55	32,02	0,75	0,57	3,25

the tests, the concentration of sodium cyanide and lime in the solution was monitored. It was found that the flotation concentrate is a refractory product for processing by hydrometallurgical methods. The recovery of gold during its sorption leaching at the original size was 36,7 %. The total consumption of cyanide for leaching is 5,13 kg / t, lime – 3,6 kg / t.

With a decrease in the size of the material to 95 % - 0,02 mm, a strong mechanochemical activation of the concentrate occurs, as a result of which its sorption activity increases, depressing and cyanide properties are enhanced. These phenomena lead to a decrease in gold recovery during the subsequent sorption leaching and an increase in the consumption of reagents for the process.

Phase analysis of the original ore revealed that a significant proportion of gold (about 15 %) present in the material is associated with minerals and quartz insoluble in aqua regia. To determine the amount of metal in the flotation concentrate bound in the specified minerals, a test was performed for its roasting followed by decomposition of the cinder in aqua regia.

Roasting is necessary for the oxidation of sulfur and the complete removal of carbonaceous matter, which exhibits sorption activity with respect to gold and can distort the results of research. Firing was carried out in two stages: at 600 °C for 6 hours and at 800 °C for 1 hour.

The material was treated with aqua regia at a pulp density of 25 % solid for 4 hours with heating to 60 - 80 °C.

The conducted test found that the minerals and quartz of the flotation concentrate insoluble in aqua regia contain 7,5 g / t of gold (in terms of the starting material). This grade is 23,3 % of the total gold present in the concentrate.

Based on the results obtained, the following conclusions can be drawn:

- the persistence of the concentrate is mainly associated with the presence of unopened fine gold in the material, a significant part of which is confined to quartz and other minerals insoluble in aqua regia;
- it is advisable to process the flotation concentrate of the deposit using chemical methods of decomposition of sulfide minerals (roasting, autoclave, bacterial oxidation, etc.) or a combination of ultrafine grinding and oxidizing technologies (atmospheric oxidation or low-temperature autoclave).

CONCLUSION

The original ore is resistant to the cyanidation process, mainly due to the presence of fine unopened gold in the material. The recovery of gold in the range from 80 % - 0,074 mm to 95 % -0,045 mm is weakly dependent on the size of the material and is 57,5 – 60,2 %. The gravity concentrate is a favorable product for its processing by the method of intensive cyanidation (gold extraction into solution – 93,9 %). The recovery of gold from gravity tailings in the cyanide concentration range of 0,05 – 0,2 % remains constant and averages 32,46 %. The total consumption of cyanide for leaching is 0,75 kg / t, lime – 3,3 kg / t. The recovery of gold from the flotation concentrate, with its sorption leaching at the original size, was 36,7 %. The total consumption of cyanide for leaching is 5,13 kg /t, lime – 3,6 kg /t.

REFERENCES

[1] Y. Liu, Y. Chang, D. Niu, F. Wang, Plant-wide optimization for gold hydrometallurgy based on the fuzzy qualitative model and interval number, Journal of Chemometrics, T 32, 12 (2018), e3077, doi: 10.1002/cem.3077.

[2] P. K. Fedotov, A. E. Senchenko, K. V. Fedotov, и A. E. Burdonov, «Concentration studies for low sulfide ores», Obogashchenie Rud, 1 (2020), 15–21, doi: 10.17580/or.2020.01.03.

[3] J. Li, J. Zhou, Deportment study and extractive metallurgy of gold and silver in a sulfide ore from China, IMPC 2018 - 29th International Mineral Processing Congress (2019), 125–134.

[4] R. K. Asamoah, EDTA-enhanced cyanidation of refractory bio-oxidised flotation gold concentrates, Hydrometallurgy, 193 (2020), 105312, doi: 10.1016/j.hydromet.2020.105312.

[5] B. Surimbayev, L. Bolotova, B. Mishra, A. Baikonurova, Intensive cyanidation of gold from gravity concentrates ina drum-type apparatus, News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 5 (2018), 32–37, doi: 10.32014/2018.2518-170X.7.

Note: The responsible translator for the English language is Alexander Garashchenko – English-speaking translator in Irkutsk, Russia.