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Assessment of the Possibility of Using Heap Leaching Technology for Processing Gold-Bearing Ore

Abstract: The article presents the results of technological studies conducted to investigate the material composition and determine the effectiveness of the heap leaching process for gold from a technological sample. These studies included laboratory tests and column tests aimed at assessing the possibilities of extracting gold from oxidized ores.

Keywords: heap leaching, gold-bearing ore, percolation, Portland cement, agglomerated ore, cyanidation, column tests.

Introduction

The heap leaching method is the most cost-effective way to process low-grade ores and industrial waste because it has much lower operating and capital costs than agitation leaching. Despite this, one of the main problems with this method is the presence of fine clay particles in the raw material, which impede the flow of the solution through the heap layer and negatively affect the efficiency of leaching.

For use in heap leaching technology, mineral raw materials must have the following basic characteristics:

- free gold content;
- the ore must have sufficient porosity and permeability;
- absence of metal impurities that compete with gold when dissolved in a cyanide solution and when extracting gold from the productive solution.

The ore's compliance with these parameters ensures the efficiency of the heap leaching process

(Fazlullin 2001), (Karaganova et al., 2002), (Surimbayev et al., 2025).

To conduct an initial assessment of the suitability of raw materials, preliminary tests are carried out on small-scale samples. These studies are usually conducted under agitation leaching conditions on ore samples, which can be achieved in industrial gold ore processing schemes using heap leaching.

The data obtained during the tests make it possible to determine the estimated degree and kinetics of noble metal extraction into cyanide solutions, estimate the consumption of basic reagents, identify possible ore preparation options (including the need for preliminary agglomeration), and select the optimal method for extracting metals from productive solutions. Based on the results of such experiments and taking into account the expected scale of processing, a preliminary conclusion is formed about the possibility and feasibility of using heap leaching technology for this type of raw material (Dementyev et al., 2004).

The paper presents the results of technological studies to determine the possibility of processing oxidized ore from one of the deposits in Kazakhstan using heap leaching technology.

Materials and research methods

The sample of gold-silver-bearing ore consists of weathered siliceous siltstone rocks and a mixture of clayey, gravelly, and crushed material (Figure 1).

Figure 1. Photograph of the initial ore sample

Table 1. Fire assay and chemical analysis results

Component	Content, %	Component	Content, %
Gold, g/t	1.18	Sodium oxide	1.90
Silver, g/t	48.78	Potassium oxide	0.60
Copper	0.0098	Silicon oxide	71.05
Nickel	0.0008	Aluminum oxide	11.00
Zinc	0.0116	Arsenic	0.156
Lead	0.3820	Antimony	0.015
Cobalt	0.0005	Total sulfur	0.37
Total iron	4.40	Sulfate sulfur	0.32
Calcium oxide	1.12	Sulfide sulfur	0.05
Magnesium oxide	0.81	Degree of sulfur oxidation	86.49

Gold and silver represent industrial value in the sample (Table 1), with an average content of 1.18 and 48.78 g/t, respectively, according to assay analysis. The content of competing metals that can interact with cyanide is insignificant: copper and zinc at 0.01%, nickel and cobalt at less than 0.001%. The content of harmful impurities – arsenic and antimony – was 0.156% and 0.015%, respectively. The sample belongs to the low-sulfide type of ore (S sulfide <1%) and, in terms of sulfur oxidation, to the oxidized zone.

Mineralogical studies have revealed the presence of free gold in the form of high-grade gold and electrum, as well as silver in the form of halides. Gold was found in the form of inclusions of various sizes in iron oxides and hydroxides. Phase analysis for gold confirmed the results of mineralogical studies, from which it follows that most of the gold (87.18%) is in free form.

Thus, the chemical composition of the tested ore is favorable for the heap leaching process.

Results and discussions

The ore is physically destructured. Small particles of silt and clay reduce the permeability of the heap, which impedes the flow of the solution and makes the leaching process less effective. For raw materials with a content of fine particles and clay exceeding 15%, preliminary pelletization is required to ensure an acceptable percolation rate (Bolotova et al 2023), (Yessengarayev et al 2018), (Bolotova et al 2020). Sieve analysis results show that crushed ore of various sizes (-50+0 mm, -25+0 mm, and -12+0 mm) contains an increased amount of particles smaller than 2.5 mm, which makes it necessary to evaluate the hydrodynamic characteristics and make a decision on pelletization.

Percolation tests were conducted for crushed ore with sizes of -50 mm, -25 mm, and -12 mm. It was found that non-agglomerated ore with a size of -50 mm meets the requirements of the heap leaching process. Ore with a size of -25 mm and -12 mm does not meet the requirements in terms of the rate of water percolation through the ore layer, which is less than 10 m/h. In this regard, tests were conducted to determine the optimal consumption of Portland cement. According to all regulatory parameters of percolation, the following modes are satisfactory for ore with a size of -25 mm and -12 mm: Portland cement consumption of 4 kg/t; water consumption of 98 – 101 l/t; pellet moisture content of about 10%. Figure 2 shows a photograph of pelletized ore. Thus, ore with a size of less than 25 mm after pelletization is also suitable for the heap leaching process.

-25 mm -12 mm

Figure 2. Agglomerated ore after 72 hours of aging

The initial assessment of ore leaching efficiency is carried out using standard bottle tests on crushed ore with a size of 80 - 90% of the -0.071 mm class. The gold dissolution rates achieved are considered to be the maximum possible, as grinding ensures complete access of gold to the cyanide solution. To assess the applicability of heap leaching technology, an additional bottle test is performed on crushed ore with a size of -2.5 mm. The experiments were carried out in a bottle agitator under the following conditions: ore sample weight 0.3 kg, solid to liquid ratio (S:L) 1:2, pH 10 - 11, sodium cyanide concentration 0.10%, leaching duration 24 hours. During the leaching process, the sodium cyanide concentration and pH of the medium were monitored, with reagents added as necessary. Based on the results of the bottle test, a diagram of the degree of metal dissolution was constructed, which is shown in Figure 3.

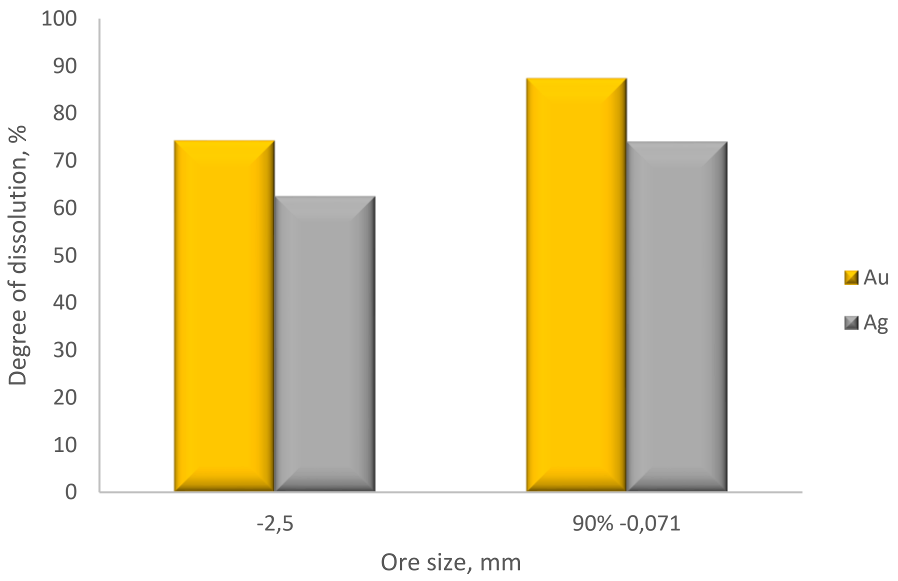

Figure 3. Degree of dissolution of gold and silver from ore based on bottle test results

The data in Figure 3 shows that ore size has a significant impact on the degree of gold dissolution. Thus, the degree of gold dissolution from crushed ore of -2.5 mm was 74%, while from ground ore with a size of 90% of the -0.071 mm class, the degree of gold dissolution increased to 87%. Particularly noteworthy is the high degree of silver dissolution, which is estimated at 62% (size -2.5 mm) and 73% (size 90% class -0.071 mm). As mentioned earlier, the ore belongs to the category of oxidized ores. As a rule, silver in oxidized ores dissolves well in cyanide solutions along with gold.

The copper and zinc content in the cyanide solution is, as expected, low – 2.33 mg/l and 2.05 mg/l, respectively. It is known that during heap leaching, copper accumulates in the productive solution as a result of repeated circulation of solutions. When its concentration exceeds 100 mg/l, special methods must be used to ensure effective gold extraction (Bolotova et al 2018), (Shalgymbayev et al 2024), (Kanaly et al 2024). For the ore being tested, this problem of accumulation of metal impurities in the productive solution will not arise.

The consumption of sodium cyanide for interaction with minerals was 0.84 - 1.02 kg/t.

The final assessment of the applicability of heap leaching technology and process modes is determined by the results of column tests. Column tests of heap leaching of gold were carried out in three columns on crushed non-granular ore with a size of -50 mm and on granular ore with a size of -25 mm and -12 mm in a closed cycle: leaching of gold from ore with alkaline cyanide solutions; sorption of dissolved gold by a sorbent; return of the solution to the leaching cycle after adjusting the sodium cyanide concentration and pH. AM-2B anion exchange resin, known for its high selectivity and efficiency, was used to extract dissolved gold from the leach solutions. It excellently sorbs cyanide complexes of gold from multicomponent solutions containing heavy metal impurities.

During the tests, the operating parameters of the process and reagent consumption were determined. The percolation characteristics of non-agglomerated and agglomerated ore were maintained throughout the process. There was no accumulation of impurity metals in the productive solutions. Gold and silver were effectively extracted with AM-2B resin.

To dissolve the gold, 31 leaching cycles were required for ore with a size of -25 mm and 12 mm, and 44 cycles for ore with a size of -50 mm. The total amount of productive solution obtained was quite large, at

2.34-2.71 m^3/t of ore. The high specific consumption of the leaching solution is due to the slower dissolution of silver.

The consumption of sodium cyanide for leaching gold from coarse ore was 0.58 - 0.67 kg/t.

Based on the data obtained, the gold and silver balance was calculated for heap leaching of gold and silver from ore (Table 2).

Table 2. Metal balance

Naming of indicators	Indicators		
Ore size, mm	-50	-25	-12
Metal extracted with ion exchange resin, g/t of ore:			
Au	0,69	0,81	0,82
Ag	12,87	21,40	24,16
Metal extracted during water washing operations, g/t of ore:			
Au	0,02	0,02	0,02
Ag	0,63	0,45	0,33
Metal content in column leaching tails, g/t:			
Au	0,44	0,39	0,31
Ag	34,04	27,28	21,32
Estimated metal content in the source ore, g/t:			
Au	1,15	1,21	1,15
Ag	47,54	49,12	45,82
Degree of metal dissolution from ore according to balance, %:			
Au	61,50	68,28	72,79
Ag	28,40	44,48	53,46
Expected metal recovery in commercial products, Doré alloy, %:			
Au	55,05	61,11	65,15
Ag	25,42	39,81	47,85

Based on the data obtained, the gold and silver balance was calculated for heap leaching of gold and silver from ore. The maximum degree of dissolution of gold (72.79%) and silver (53.46%) was achieved with an ore size of -12 mm. At a size of -25 mm, the indicators decrease to 68.28% and 44.48%, respectively, and at a size of -50 mm, to 61.50% and 28.40%.

Conclusion

Studies have shown that heap leaching is a highly effective method for processing oxidized ore. For optimal processing of this ore, it is recommended to crush it to a size of -12 mm with preliminary pelletizing. The estimated extraction of gold in the Doré alloy during industrial processing of oxidized ore will be 65.15%, and silver - 47.85%, with an initial content in the ore of 1.15 g/t and 45.80 g/t, respectively.

The results obtained confirm the possibility of effective processing of oxidized ore by heap leaching, which opens up prospects for further industrial application of this method.

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