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Gold and Silver Extraction from Persistent Arsenopyrite Gravioconcentrate

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Abstract

Results of the studies of gold and silver extraction from persistent arsenopyrite gravioconcentrate are presented, starting with mechanochemical breakdown of the concentrate, subsequent cyanide leaching, electrolytic extraction of the metals from cyanide solutions, and ending with obtaining the finished products in the form of metal alloy. The cycling use of cyanic solutions after electrolysis in leaching process is evaluated. Electrolytic extraction of gold and silver was carried out on the cathodes made of carbon fibre materials, followed by thermal treatment. The final products with gold and silver content up to 95 mass % were obtained. The results of subsequent industrial tests at a gold production plant showed that the use of mechanochemical breakdown and an experimental-industrial activator to obtain gold and silver from persistent arsenopyrite gravioconcentrates of the deposits situated in the north-eastern part of Kazakhstan allows an increase in the rate and degree of gold and silver extraction.

Keywords: arsenopyrite gravioconcentrate, mechanochemical activation, leaching, electroextraction, gold, silver, industrial tests, carbon fibre electrodes

INTRODUCTION

Gold recovery from persistent concentrates and ores attracts increasing attention during recent years. It is assumed that a substantial part of gold will be mined from persistent ores (pyrite, arsenopyrite *etc.*). To recover gold and silver from these concentrates, various technological schemes are developed, involving the methods of pyro-, hydrometallurgy, autoclave, bacterial treatment, individually or in combinations [1–5]. A promising but not widespread method is fine grinding, including mechanochemical treatment of concentrates followed by the dissolution of gold in cyanide solution [1–4, 6, 7].

It was demonstrated in [8] that gold dissolution in cyanide solutions in contact with sulphide minerals (for example, with pyrite) enhances substantially as a result of mechanochemical activation of these minerals.

In this process, gold in contact with pyrite is an anode, while pyrite is a cathode. Pyrite is one of the main minerals of arsenopyrite gold-containing ores. Gold dissolution is performed due to the operation of a short-circuited electrochemical system (SES): gold – pyrite – sodium cyanide solution.

A complicated and substantially different composition of the ores from different deposits does not allow predicting the behaviour of gold and silver at different stages of hydrometallurgical technology. Because of this, it is necessary to carry out research and technological tests of the processes under development, from the initial treatment of the products from specific deposits to the final product, preferably in the form of the metal, directly at the gold-mining works.

It is evident that mastering of the technology of gold and silver mining may proceed along the route to intensify all the stages of the technological process of metal recovery from ores.

In the present work, we report on the results of the studies carried out at a gold-mining plant, along with the development of the technology of gold and silver recovery from the persistent arsenopyrite gravioconcentrate. The processes under study included several stages:

1) mechanochemical treatment of the concentrate;

2) cyanide leaching of gold and silver;

3) electrolytic recovery of gold and silver from clarified solutions on the flow three-dimensional electrodes made of carbon fibrous materials;

4) circulating use of solutions in the electrolysis – leaching cycle.

Subsequent industrial tests of the process and apparatus for the mechanochemical treatment of the arsenopyrite gravioconcentrate of ore from the Vasilkovskoye deposit were carried out on the basis of the results of these investigations.

EXPERIMENTAL

Laboratory studies

Mechanochemical treatment of the gravioconcentrate was carried out at a M-3 planetary centrifugal mill under different grinding conditions. When choosing the conditions of mechanochemical activation, the following goals were put forward: 1) to achieve the high activity of the material; 2) to obtain high dispersity of the material; 3) to provide minimal possible concentrations of nonferrous metals and iron in solution during gold and silver leaching. So, gravioconcentrate was treated in the planetary mill in different media: air, water, water-alkali. The varied parameters were: 1) activation time from 0.5 to 10 min; 2) activation medium: aqueous, with water content 5 to 40 % , water-alkali, with water content 25 % and calcium oxide up to 5 kg/t of the concentrate.

Cyanide leaching was carried out in a bottle agitator using the mode applied at the Vasilkovskoye experimental gold recovery plant (EGRP): sodium cyanide concentration 0.03–0.04 %, calcium oxide 0.03–04 %, the liquid to solid ratio L : S = 3 : 1.

Electrolytic recovery of gold and silver from clarified solutions was carried out according to the procedure and set-up described in [9, 10]. The electrolyzer was composed of one cathode chamber and two anode chambers. The overall cathode surface area was 60 cm^2. Electrode spaces were separated with an ion exchange MK-40-2L membrane, the anodes were made of platinum-coated titanium. Carbon fibre materials (CFM) VVP-66-95, NTM-100, NTM-200, KNM, VINN-250, VNG-30 differing from each other in specific surface and specific conductivity were used as the cathode. The properties of these materials were described in [9, 10].

Process parameters that were varied during the electric recovery of metals included: a) current density 200–2000 A/m^2; b) CFM cathode thickness 2–25 mm; c) the rate of solution flow through the electrode volume 2–40 mL/s through 1 cm^2 of the overall electrode surface. Electrolysis was carried out in the direct-current mode, *i.e.*, during a single passage of the solution through the electrode volume.

Metal leaching from the concentrate with the cycling use of solutions was carried out with the correction of solution composition with respect to sodium cyanide and calcium oxide, and without any correction.

Industrial tests

Industrial tests were carried out using an E-UEMP continuous-mode activator designed according to the requirements specification prepared by the authors of the present paper and built at the SKB GOM (Special Design Department for Ore Mining and Processing Machines) in agreement with the schematic of the AMA device [11].

The instrumental arrangement of concentrate activation and metal leaching included an agitator for pulp preparation, E-UEMP activation of continuous operation, agitator for leaching, pumps for pulp pumping. The working volume of the activator cylinder was 3 L, the mass of balls 10 mm in diameter was 3 kg, the frequency of cylinder rotation was 600 r.p.m.

The pulp with the ratio L : S = 2 : 1 and pH ~ 11 was prepared in the mixer, supplied to the activator at a rate of 0.1 –0.6 m^3/h, and then subjected to cyanation in an open-type agitator with mechanical mixing for 6 h; the concentration of sodium cyanide was 0.1 %, calcium oxide 0.1 % (solution pH was 10.8).

Analysis of the solutions and gold-containing products was carried out at the Assay Analytical Laboratory of the Vasilkovskoye ore mining and

TABLE 1

Rational analysis of the ore from the Vasilkovskoye deposit

Forms of gold occurrence	Content, g/t	Distribution, %
Free	0.9	27.3
In aggregates with arsenopyrite and quartz	1.3	39.4
In sulphides	0.5	15.2
In quartz, in rock	0.6	18.6

Note. The size of gold particles is 0.001—0.01 μm.

processing enterprise using the procedures accepted in the gold mining industry (assay analysis, atomic absorption analysis, granulometric, mineralogical and rational analyses) [12].

RESULTS AND DISCUSSION

The chemical composition of gravioconcentrate: gold 5–50 g/t, silver 16–20 g/t, copper 0.29–4 %, iron 4–9 %, zinc 0.1 –0.7 %, lead 0.17 %, arsenic 1.6–5.1 %, quartz 55.7 %, total sulphur 2.05 %. According to the data of mineralogical analysis, the gravioconcentrate contains quartz 56 %, sulphide minerals (pyrite and arsenopyrite) 30 %. Table 1 shows the results of the rational analysis of the ore from the Vasilkovskoye deposit.

One can see that the ore contains fine gold associated with pyrite and arsenopyrite, and relates to persistent (difficult-to-treat) ores.

The conditions for the mechanochemical treatment of the concentrate providing the best recovery of gold during subsequent cyanation were determined: a) in the aqueous medium, water content 30–40 %; b) in the water-alkali medium, water content 25 %, calcium oxide 2–3 kg/t of the concentrate. The degree of gold and silver recovery from the mechanochemically activated concentrate by means of cyanation was 91.0–95.2 and 86.2–93.7 %, respectively; gold content in the solution was 9.9–11.5, silver 8.1–9.2 mg/L.

For comparison, cyanation of the samples was carried out without their mechanochemical activation. For this purpose, we used a sample of initial gravioconcentrate and the samples of gravioconcentrate ground in the ball mill or in a vibratory attritor, containing 7, 50 and 98 % particles, respectively, with a size of –0.071 mm. In spite of a substantial increase in the degree of product comminution (from 7 to 98 %), gold recovery by means of cyanation increased by only 5–6 % and did not exceed 63 %, silver recovery increased by 2.5 %.

After leaching of the activated concentrate, electrolysis was carried out in the solutions of the following composition, mg/L: gold 9.9–11.5, silver 8.1–9.2, copper 20–450, zinc 4–48, iron 0.1–51, sodium cyanide solvent 0.03–0.01 %, pH 10–12. The best results were obtained with the use of carbon fibrous materials: VVP-66-95, NTM-100, VINN-250. These materials allowed gold recovery from the above-indicated solutions by 88–92 % during a single pass of the solution through the electrode, which provides the process productivity 50–70 m^3 of the solution per 24 h per 1 m^2 of the overall cathode surface are in the electrolyzers of EU-10V type [13, 14]. Carbon fibre materials with the recovered metals was subjected to roasting and fusing. The total gold and silver content in the cathode metal was 90–95 % depending on the electrolysis mode.

Investigation of the cycling use of solutions in the electrolysis – leaching cycle showed that the solutions without the correction of their composition with respect to sodium cyanide and pH may be used without worsening of the parameters of leaching process not more than 2 times, and then they are to be corrected with respect to the concentration of sodium cyanide. The solutions corrected after each electrolysis stage allowed obtaining a high gold recovery degree, in some cases even exceeding the recovery by the fresh solution by 2–3 %.

Below we present the results of industrial tests of the activator of continuous operation and the technology of mechanochemical activation of gravio-

TABLE 2

Granulometric composition of initial concentrate

Particle size, mm	+1.6	+1.25	+0.8	+0.5	+0.4	+0.125	+0.074	–0.07
Percentage of the fraction, %	1.2	1.2	5.2	10.0	8.0	53.8	13.5	10.2

TABLE 3

Granulometric composition of activated gravioconcentrate

Particle size, mm	+0.02	+0.01	+0.005	−0.005
Percentage of the fraction, %	0.6	17.2	62.4	19.2

TABLE 4

Results of cyanide leaching of gold from the gravioconcentrate

Gravioconcentrate	Gold recovery into solution for 6 h, %
Initial	67
Activated, at the rate of pulp input into the activator, m^3/h	
0.11	84
0.18	90
0.40	90

concentrate. The advantages of the mechanochemical activation are obvious from the results on the granulometric composition of the initial gravioconcentrate (Table 2) and activated one (Table 3). The particle size in the initial concentrate varies within a broad range (see Table 2), which is known to bring substantial complications into the fine grinding of the product. Mechanochemical treatment involving activation with the rate of pulp input into the activator 4 m^3/h allowed obtaining a rather uniform product (see Table 3).

It follows from the results shown in Table 4 related to the cyanation of the initial and activated gravioconcentrates that mechanochemical treatment in the continuous mode allowed a substantial increase in the degree of gold recovery from 67 to 90 %, and the rate of gold leaching increased by a factor of 1.4–1.9. This is the evidence of the high efficiency of the developed mechanochemical method of gravioconcentrate treatment and the tested design of the activator.

The consumption of electric energy for the treatment of 1 t of gravioconcentrate was 20–25 kW · h, and the optimal rate of pulp flow was 0.2–0.4 m^3/h.

The results of industrial tests served as the basis for the industrial application of the technology and the activator by the personnel of the gold recovery plant for the treatment of persistent concentrate of one of the deposits in the northern part of Kazakhstan. The concentrate contained gold 65.5 g/t, pyrite 70 %, the size of gold particles 0.07–0.20 mm; zinc and copper sulphides were also present. The amount of the treated concentrate was 3200 kg, the time of activator operation was ~30 h.

The activator exhibited reliable, stable operation. The consumption of electric energy was 20–25 (kW · h)/t of the concentrate.

CONCLUSION

Results of the studies carried out at the Vasilkovskoye EGRP showed that the developed technology of processing the gold and silver containing arsenopyrite concentrate involving mechanochemical treatment followed by leaching with cyanide solutions and electrolytic recovery of precious metals from the clarified solutions onto the cathodes made of carbon fibrous materials allows a substantial improvement of gold and silver recovery process, an increase in the degree of their recovery from the concentrate into the solution to 91.0–95.2 and 86.2–93.7 %, respectively, efficient recovery of the metals from solution, multiple uses of solutions in the electrolysis – leaching cycle, The final product is obtained in the form of metal alloys with the total gold and silver content up to 95 %.

Results of industrial tests showed that mechanochemical treatment and the activator used for the recovery of gold and silver from persistent arsenopyrite gravioconcentrates from the deposits in the northern part of Kazakhstan allowed an increase in the rate and degree of gold and silver recovery, which is in good agreement with the results of the investigations.

REFERENCES

1 Sedelnikova G. V., *Zolotodobyvayushchaya Promyshlennost*, 2015, Vol. 72, No. 6, P. 14–22.

2 Zakharov B. A., Meretukov M. A., Gold: Persistent Ores [in Russian], Moscow, Ruda i Metally, 2013. 452 p.

3 Lodeyshchikov V. V., Technology of Gold and Silver Recovery from Persistent Ores [in Russian], Irkutsk, Irgiredmet, 1999. 342 p.

4 Sudakov D. V., Chelnokov S. Yu., Rusalev R. E., Elshin A. N., *Tsvetnye Metally*, 2017, No. 3, P. 40–44.

5 Sedelnikova G. V., Kurkov A. V., Smirnov K. M., *Tsvetnye Metally*, 2016, No. 8, P. 24–32.
6 Varentsova V. I., Varentsov V. K., Boldyrev V. V., *Zhurn. Prikl. Khimii*, 1990, Vol. 63, No. 3, P. 560–565.
7 Varentsova V. I., Varentsov V. K., Boldyrev V. V., *Izv. SO AN SSSR. Ser. Khim. Nauk*, 1983, Issue 5, No. 12, P. 114–116.
8 Varentsova V. I., Varentsov V. K., Lukyanov V. O., Boldyrev V. V., *Izv. SO AN SSSR. Ser. Khim. Nauk*, 1989, Issue 5, P. 32–36.
9 Varentsov V. K., Modern Problems of Technical Electrochemistry. Part 1. Three-Dimensional Flow Electrodes [in Russian], Novosibirsk, Publishing House of NGTU, 2005. 118 p.
10 Barentsov V. K., Koshev A. N., Varentsova V. I., Modern Problems of Electrolysis and the Problems of Process Optimization in Reactors with Three-Dimensional Carbon Electrodes: a Monograph [in Russian], Penza, PGUAS, 2015. 288 p.
11 Molchanov V. I., Selezneva O. G., Zhirnov E. I., Activation of Minerals during Grinding, Moscow, Nedra, 1988. 208 p.
12 Zelenov V. I., Procedure for the Investigation of Gold-Containing Ores, Moscow, Nedra, 1978, 302 p.
13 Varentsov V. K., *Chemistry for Sustainable Development* [in Russian], 1997, No. 2, P. 147–156.
14 Varentsov V. K., Modern Problems of Technical Electrochemistry. Part 3. Electrochemical Reactors and Processes with Flow Carbon Electrodes [in Russian], Novosibirsk, Publishing House of NGTU, 2007. 123 p.