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FEASIBILITY OF MINING GOLD BY UNDERGROUND PLACER LEACHING

G. G. Mineev and A. M. Shutov

The raw materials base for placer mining has become more varied and complex with respect to mining and geological conditions. Many placers lie at considerable depths, so that dredgers cannot be used; the number of sites affected by permafrost, which can be exploited only with some losses, has increased [1]. Even in the treatment of thawed placers the losses of gold are considerable – 10-20%, depending on the characteristics of the raw material, in some cases up to 30% – owing to the low extraction of fine gold in the sluices. Gold finer than 0.1 mm cannot be extracted by dredging, and the −0.3 + 0.1-mm fraction is extracted only to the extent of 50-60%. For economic reasons there are only limited possibilities of using more efficient equipment than sluices (jiggers, screw separators, etc.) in the main operations.

From literature sources it appears that to cope with placers with difficult access or very find gold, a promising method is that of underground leaching, which has already been successfully used in related branches of industry [2-6]. Solution of this problem would increase the available gold resources.

Underground leaching is used to work a number of deposits of nonferrous and rare metals and other minerals (uranium, copper, sulfur, and salt). Outside the USSR, up to 20% of the copper is obtained every year by underground and dump leaching. The end product from this technology is 1.5-2 times cheaper than that from the usual mining methods. About 2/3 of the world output of sulfur is obtained by underground melting with hot water. Underground leaching is used to obtain 25-30 million tons of rock salt per year.

Only patents are known for underground leaching of gold. As early as 1896 a patent was issued in Russia on "A method of extracting gold and other noble metals by direct leaching of deposits" [2]. The method was proposed for working lean deposits which would be very difficult or impossible to work by the usual methods. The solvent for the noble metals is introduced directly into the productive seam, and the resultant gold solution is extracted by pumping or drainage and then processed. In 1945 Skuratov [7] suggested a method of working gold-bearing placers by underground cyaniding. He proposed that for the process of extracting gold underground water currents in gold-bearing placers should be saturated with cyanide solutions.

Neither method has found industrial applications, owing mainly to the lack of easily available nontoxic solvents for gold and experience in underground leaching of ores. The problem has become urgent in recent years, especially owing to the present-day achievements of the technology of underground leaching of nonferrous and rare metals.

Among the few reagents which have been long known for the solution in gold there are aqua regia, chlorine water, and cyanides. At present, leaching with cyanide solutions is the main method of hydrometallurgical processing of gold-bearing ores and their beneficiation products. The chief advantage of cyanide is its high efficiency and selectivity for gold; its main drawback is its high toxicity. Earlier, industrial use was made of the the chlorination method, which can recover gold from tailings, but in two or more successive [illegible] treatment. [illegible] solutions of chlorine have a collective action, and are very aggressive [illegible].

[illegible] Irkutsk [illegible]. Translated from Fiziko-Tekhnicheskie Problemy Razrabotki Polez[illegible] –

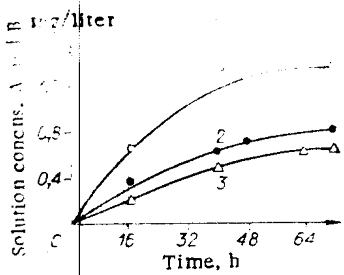

Fig. 1. Dynamics of leaching of gold by solutions of acetone cyanohydrin (1, 2) and sodium cyanide (3) at 5°C in the presence of added oxidant (1, 3) or without it (2). Leaching was effected by 0.1% solutions in terms of NaCN.

The search for new nontoxic or slightly toxic gold solvents has lately been redoubled, owing to the increasing importance of the underground leaching of gold-bearing ores, which cannot be effected on a large scale without the use of harmless solvents. There is some interesting information [8, 9] on the leaching of gold from ores by alkaline solutions of malononitrile $CH_2(CN)_2$, bromomalononitrile $BrCH(CH)_2$, and potassium cyanoform $KC(CN)_3$. It is though that these compounds hydrolyze to form stable nontoxic hydrocarbon compounds:

$$CH_2(CN)_2 \rightleftarrows CH(CN)_2^- + H^+,$$
$$BrCH(CN)_2 \rightleftarrows BrC(CN)_2^- + H^+,$$
$$KC(CN)_3 \rightleftarrows C(CN)_3^- + K^+.$$

By leaching quartz ore with a particle size of −0.15 mm containing 12.4 g/ton of gold with malononitrile solution (0.05%), 95% of the metal was extracted in 24-h working with L : S = 3 : 1 and pH = 8–12 (created by adding lime).

There are certain prospects for leaching gold from poor ores with ammonium humate solution, since this compound is adequately efficient, its production technology is simple, and the raw material is easily available [10, 11]. As a nontoxic solvent for gold it is possible to use amino acids [12, 13], especially a technical mixture of these compounds. At present these solvents are still in the stage of detailed laboratory investigation and technological tests.

An effective solvent for gold is acetone cyanohydrin $(CH_3)_2COHCN$, a representative of the class of α-hydroxynitriles. In an alkaline medium, acetone cyanohydrin hydrolyzes, splitting off acetone and CN^- ions. Its action on gold is similar to that of sodium cyanide, but it has high kinetic activity [14].

Thus, for developing methods and technologies for underground leaching of gold-bearing placers on a pilot scale we can recommend only sodium cyanide and acetone cyanohydrin. There may be prospects for testing other, nontoxic gold solvents in this process.

When toxic solvents are used for underground leaching of gold, it is of the first importance to consider measures to prevent leakage of the solutions and for efficient detoxification of the effluents. In this connection the most favorable placers for leaching are in the permafrost, because it is possible, without special expenditure, to create isolated water-impermeable sites.

Preliminary research has begun on the leaching of gold from frozen placers. Below we give experimental data on the solution of gold by solutions of acetone cyanohydrin and sodium cyanide at low temperatures (5°C) and on the use of various oxidizing agents instead of (or as well as) oxygen; we will describe planned processes and considerations on the organization of the process on the pilot scale. Since the kinetics of dissolving gold in cyanide solutions at low temperatures has been discussed by Sorokin [15], we paid particular attention to the solubility of the metal in acetone cyanohydrin in comparison with cyanide. The experiments were performed on material with a particle size of −2 + 0 mm containing 3 g/ton of the metal. The mean gold particle size was 0.2–0.3 mm. Leaching was effected in a refrigerator at + 5°C with stirring of the pulp (L : S = 2 : 1). To prepare the solutions we used 96% acetone cyanohydrin (53% in terms of NaCN) and sodium cyanide of chemically pure grade.

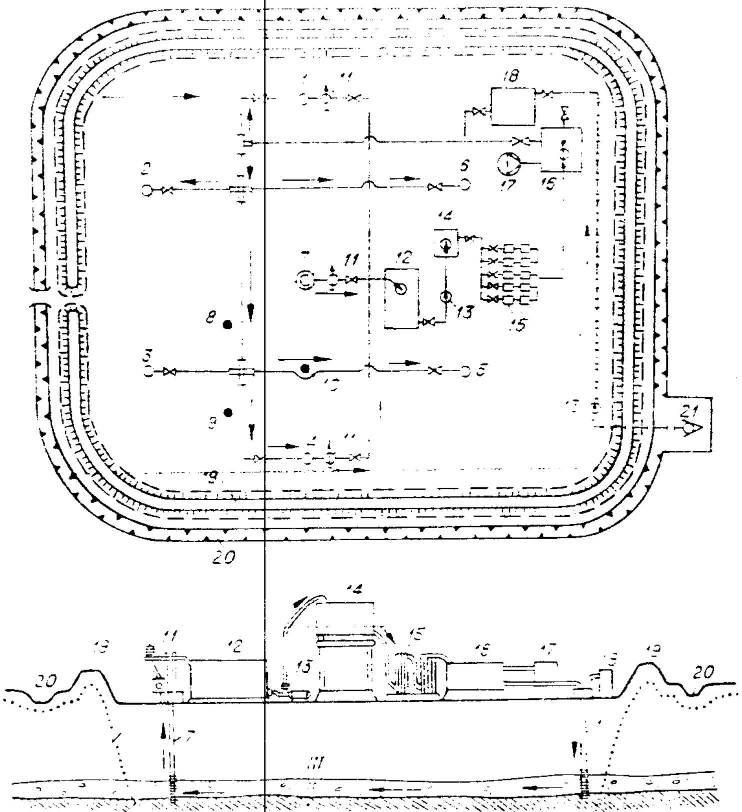

Fig. 2. Diagram of pilot plant for underground leaching of gold from frozen placer deposit.

It is known that the rate of solution of gold in cyanide solutions decreases with falling temperature. The process can be speeded up at low temperature by means of special oxidizing additives (Fig. 1). Thus, the degree of solution of gold in acetone cyanohydrin after 72 h increases from 0.66 to 1.3 mg/liter (practically double) as we go from pure solution to one with oxidant (curves 1 and 2). The cyanide solutions were less effective (curve 3). Solution of gold is practically complete after the first 45-50 h of processing the material.

Acetone cyanohydrin supplies not only cyanide ions but also acetone, which, according to Lebedev and Kakovskii [14], depassivates gold and thus exerts a favorable influence on the process of solution of the metal. This explains the fact that acetone cyanohydrin has a greater technological effect than sodium cyanide.

We compared the expenditure of the reagents (in terms of NaCN) for leaching of gold by solutions of acetone cyanohydrin and sodium cyanide with various doses of oxidizing agent. The consumption of reagents increases linearly with the load of oxidizing agent. The consumption of acetone cyanohydrin (in terms of NaCN) is about half that of sodium cyanide.

Acetone cyanohydrin has other advantages over cyanide: in pure form it is nontoxic – only its aqueous solutions are toxic; according to Lebedev and Kakovskii [14], this solvent reacts less strongly with accompanying minerals; and it is 1.2 times as cheap as sodium cyanide. The cyanohydrins are a wide class of compounds; some of them are wastes from the chemical industry (e.g., lactonitrile in the production of acrylonitrile).

It is interesting to study the possibilities of using cyanohydrins instead of cyanides in underground leaching of gold-bearing placers.

Pilot studies have been made of the underground leaching of gold from frozen placers. Before direct leaching of the gold-bearing seam, it is envisaged that it should be thawed out by the usual methods. The apparatus (Fig. 2) includes six injection boreholes (1-6), one extraction borehole (7), and three observation boreholes (8-10) arranged in a ring with the extraction borehole in the middle. The gold solvent passes through the gold-[illegible] seam [illegible] 11 from the extraction borehole to receiver 12. The clarified gold-[illegible] 13 into [illegible] vessel 14, from which it flows into sorption

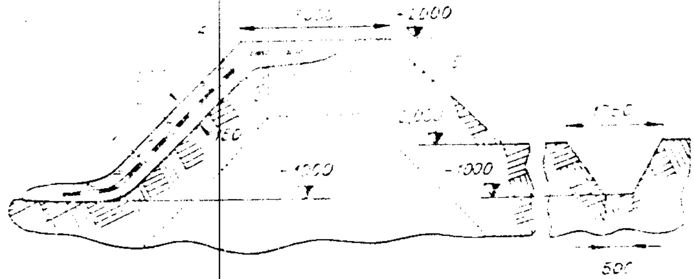

Fig. 3. Vertical cross section structures (measurements in millimeters).

columns 15 which trap the metal. The dearated solutions are concentrated in vessel 16, where they are fortified with the main components. The apparatus operates in a closed continuous cycle with automated principal technological processes; it also permits the direction of the flow of solvent in the seam to be reversed (in which case boreholes Nos. 1 and 4 are connected in the extraction circuit), with the aim of studying the process of leaching gold by a linear scheme and to avoid silting up of the gold-bearing seam.

Measures are envisaged to prevent filtration of the solutions outside the leaching zone. The perimeter of the experimental site is guarded around the perimeter by frost-protection embankment 19 to prevent possible leakage of solvent from the groundwaters of the active layer, and also by a raised ditch 20 for removal of water formed by atmospheric precipitation and by seasonal thawing of the frozen layer. A vertical cross section of these structures is shown in Fig. 3.

After completion of leaching and washing out of the dissolved gold, the seam is detoxified with solutions of bleaching powder from vessel 18 until solutions pumped out from it give a negative reaction for CN^-.

Our test on the recommended equipment for underground leaching of gold from sand enables us to obtain the necessary hydrodynamic and technological data and to determine the possibility and prospects for this technology for utilizing uneconomic and uncommercial deposits in specific mining-geological conditions which complicate the work and make it more expensive. For underground leaching we can recommend certain deposits in the northeast [of the USSR] which show promise but are not being exploited owing to the failure to find a way of working them. Larger-scale economic calculations revealed that in central Siberia and Kazakhstan it is possible to use underground leaching of placers along ridges with 0.2 g/m^3 of gold, and in the far north [of the USSR], those with 0.5 g/m^3 or more.

CONCLUSIONS

1. When toxic solvents are used in underground leaching of gold, the first question which arises is how to prevent leakage of the solutions and how to efficiently detoxify the effluent. In this connection the most favorable objects for leaching are placers in permafrost, because in this case it is possible to create isolated water-impermeable sites (districts).

2. At low temperatures the greatest effect can be obtained with acetone cyanohydrin in combination with moderate additions of oxidizing agent. Other conditions being constant, the oxidizing agent nearly doubles the rate of solution of the metal without decomposing the acetone cyanohydrin, and thus without increasing its consumption.

3. A pilot project for underground leaching of gold from a frozen placer has been developed and is recommended for testing.

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