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Applicability of in-situ leaching and divided blasting combination

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Abstract. The article gives the theoretical and experimental substantiation for application of in-situ leaching combined with divided blasting of ore blocks. Blasting also involves injection of hot steams of chemical solutions with active oxidizers in rocks. The authors discuss the designs of explosive charges with inserted shells of chemical agents in them for the divided blasting and injection as well as the compositions of agents for in-situ leaching of gold, silver, molybdenum and copper leaching from ore pillars and deep-level rebellious ore.

1. Introduction

Depletion of ore reserves at the closing stage of mining under resultant change in stress state of rocks [1] actually requires transiting mining systems with backfill and/or in-situ leaching widely applied in the uranium and copper production industries. In case of ore bearing such valuable components as gold, silver, molybdenum, wolfram, nonferrous metals and rare earths, the specified method, despite its evident advantages over conventional geotechnologies, is only used sporadically in the form of dull-scale experiments. The primary causes are the difficulty of oxidation of most ore types and selective extraction of valuable elements from them, high density as well as structural and textural features of ore bodies, which governs low permeability of broken rock blocks for leaching solutions. It is possible to improve efficiency of in-situ leaching and stimulate recovery of useful components from rebellious ore by increasing temperature of preparation and/or leaching solutions and by raising concentration of highly active oxidizing and complexing agents in them. The technical implementation of this approach involves special structure borehole charges, namely, thin-walled bulbs containing various chemical agents are arranged along the axis of an explosive charge [2]. During blasting, the chemical agents mix with explosion gases, and the provoked chemical reactions form a set of high-active oxygen-bearing compounds, including ion-radical and radical forms (Figure 1). Generated under heating of the solutions by blasting, steams bearing hydrated active ion-radical and radical forms of oxidizes are pushed by residual pressure into opening micro-cracks.

Bottom-up divided blasting by sections, in particular, Vertical Crater Retreat method VCR widely used in Canada [3, 4] is known to produce the most uniform fragmentation with the dominant yield of particle size – 20 mm by the limited length charges. By placing thin-wall plastic shells with chemical agents in the center of such explosive charge, it is possible to ensure quasi-spherical propagation of blast waves as well as oxidizing solutions and steams. In such conditions, the ore in the blasted section will be uniformly broken and soaked with condensed steams of chemical agents injected in the blast-generated



micro-cracks and pores. Such blasting treatment enlarges the ore–solution contact area as well as increases concentration gradient of solutions and dissolved metals in the system of film and pore water–leaching solution flows, which accordingly stimulates diffusion processes of mass exchange.

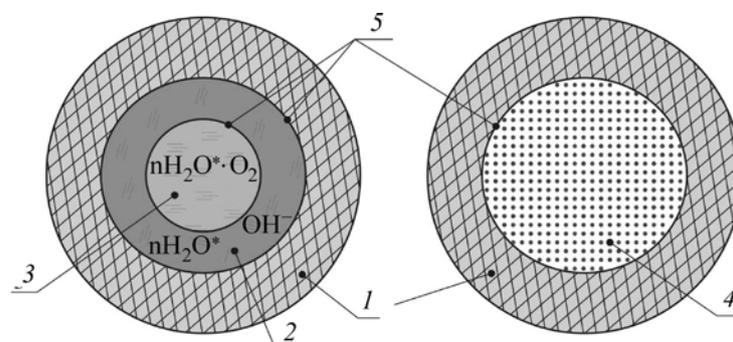


Figure 1. Injection-type charge structure: 1—explosive; 2—solution 1 (catolyte); 3—solution 2 (anolyte); 4—explosive with cenospheres; 5—plastic shell.

Under divided blasting, a thin layer of ore is broken, or bottomhole zone of long vertical holes drilled in an ore block. The unblasted parts of such holes can be used to feed activation solutions (water-and-gas emulsions) to pretreat rock mass. Such solutions of active hydrated oxidizers and/or complexing agents are prepared using a special photoelectrochemical reactors equipped with a system of electrodes and an ultraviolet source. The hydrated compounds with active oxygen accelerate oxidation of iron, copper and sulfur with the concentration of the resultant sulphates in film water.

Then, the next upper-lying section of the hole is loaded with the same structure explosive charges, and the technology cycle is repeated until the blasting front approaches the block roof. After that, all broken ore soaked with the preparatory solutions is cured, which results in the oxidation of a certain portion of iron and sulfur as well as the primary leaching of copper (in the mode of diffusion). The main stage of in-situ leaching and metal extraction from broken ore by solutions of chemical agents is better to be carried out by steps. First, an ore block is fed with preparatory alkaline–peroxide, sulfuric acid–peroxide, hypochlorite and peroxide–carbonate solutions with active oxidizers (dependent on mineralogical composition of ore and enclosing rocks, as well as on physicochemical properties of commercial-value metals). For instance, the injection-and-blasting treatment of skarn ore with high carbonate modulus can use oxygen-saturated solutions and alkaline photoelectrically activated solutions which will mix with hot explosion gases and form hydrated peroxide compounds. In the injection-and-blasting treatment of gold, copper and complex ore before leaching, for the conversion of sulphide and sulphosalt minerals to sulphate form, or for the oxidation of carbon-bearing and organic shots, the most effective agents are sulfuric acid and group of peroxide compounds of hydrogen and oxygen, including hydric dioxide and residual hydroxyls. Thermobaric activation of a mixture of sulfuric acid and a solution of peroxide–hydroxyl compounds, due to ionization of hydrogen, creates a highly active plasma-like medium containing both hydrated ions and radical-ion water clusters generally represented by the compounds of the type of $(\text{H}_2\text{O}\cdot\text{HO}^-(\text{H}^+\cdot\text{H}^-)\cdot\text{O}^*\cdot 2\text{H}_3\text{O}^+)$, as well as hydrated active, e.g. sulfate, groups:



After the preparatory treatment of ore by active oxidizing solutions before leaching, broken ore is subjected to dynamic penetration–infiltration, infiltration and seepage of working solution containing complexing and oxidizing agents for the valuable ore components. Removal of dissolved and leached elements can be carried out using drainage raises or orepasses. At this step of in-situ leaching, metal recovery from ore uses mostly chloride solutions with active oxygen-bearing compounds synthesized in the photoelectrochemical reactor. In particular, the best fitted method for gold recovery is a chloride–peroxide system (cyanides are applicable in mines after major preparation and expensive

environmental protection, thiosulphates and thiocarbamides decompose under intense thermobaric effect). In-situ leaching of molybdenum from quartz–molybdenum ore is advisable to include cyclic treatment of ore by sodium hypochlorite solution and peroxide–carbonate solution resultant from photoelectrochemical treatment of soda solution.

The proposed method on in-situ leaching of ore blocks with pretreatment by the divided injection-and-blasting is applicable in the additional extraction of ore from pillars, and in deep-level mining.

2. An example of in-situ leaching application

An application object for the discussed method of activated leaching may be the Udokan cupriferous sandstone deposit.

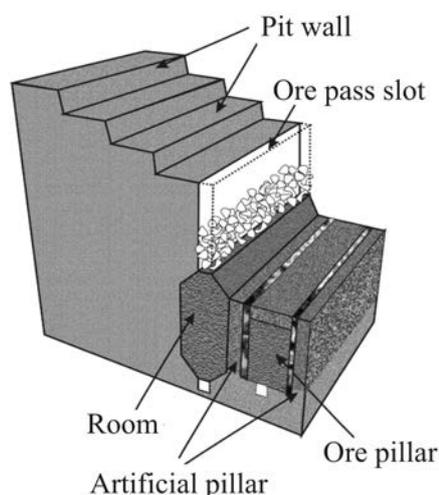


Figure 2. Schematic of the proposed combination in-situ leaching method.

For deep levels of Udokan operations, it is proposed to use a combination of the conventional underground mining system with backfill and in-situ leaching in blocks (Figure 1). Rich ore (copper content of 15–20 %, the portion in the total reserves is 5–7%) is extracted from pillars of the rebellious crude ore mining by cut-and-fill, and metals are later leached after treatment by the injection-and-blasting method. For safe mining in the seismically active Udokan deposit and to eliminate leakage of leaching solution in faults and fractures, it is expedient to use backfill of two types: cemented paste backfill along the boundary of rooms and “dry” backfill composed of run-of-mine complex ore and sulphide ore from open pit mines in the center of rooms. The main component of the cemented backfill should be mill tailings of rich sulphide ore. The tailings will be sulfating (for 5–10 years), i.e. it will become possible to recover copper and associates from the backfill, which means wasteless mining. Ore pillars in stoping in rich chalcocite–bornite ore are composed of mineralized sandstone with dominating sulphide minerals of finely impregnated bornite or (much more seldom) chalcocite and chalcopyrite. This implies economic inexpediency flotation. For this reason, after copper and silver leaching from disintegrated mineralized “dry” backfill, such ore pillars can be subjected to in-situ leaching and chemical treatment. Copper can be leached from disintegrated ore pillars in the pulse static mode (as per Professor Lunev’s classification), which means alternating cycles of ore soaking with active sulfuric acid–peroxide solution, curing, discharge of pregnant solution and feed of re-activated solutions to the upper part of blocks for the next cycle of treatment until the solutions contain the required concentration of copper. During deeper level mining in the Udokan deposit, leaching of metals can grasp overall ore body rather than backfill and pillars.

The experiments on leaching of copper, silver and gold from the Udokan sulphide ore (bornite–chalcocite paragenesis) by active solutions produced in the lab-scale photoelectrochemical reactor involved coarse samples (average size of 30 cm) 10.5 kg in weight. A sample contained 17.82% of

copper, 140.5 g/t of silver and 0.28 g/t of gold. First, crushed ore sample was fed with sulfuric acid solutions with active forms of oxygen synthesized by combining the processes of pre-aeration by bubbles, stage-wise electrolysis and photolysis of the initial aqueous solutions of sulfuric acid. Once a day 250 l batches of sulfuric acid–peroxide solutions were fed in the sample until this modeled in-situ leaching block reached a solid : liquid ratio of 10:1, i.e., the total volume of active sulfuric acid solution in the sample reached 1 l. Then, within 6 days, the solution was periodically (once a day) discharged, re-saturated with activated oxygen (bubble aeration after ultraviolet radiation) and again fed in the sample. Upon completing the “sulfuric acid” cycle of leaching, the primary pregnant solution was discharged and the liquid sample was sent for the analysis. According to the analysis outcome, recovery of copper and silver in pregnant solution made 26.7 and 3%, respectively, in 10 days. No gold was observed in the solution. Considerable content of micron native silver and cerargyrite in the cement of cupriferous sandstone, as well as in chalcocite and bornite (alongside with dispersed gold) predetermined the second-stage leaching with active solutions of sulfuric acid and nitric acid and the third-stage leaching with chloride groups. The chloride groups, the basis of which is hydrated meta-stable hypochlorous acid HClO, were prepared on the photoelectrochemical reactor and used at the closing stage of dispersed gold and copper leaching. Finally, the recovery of copper was 82.6%, which is comparable with the performance of the conventional circuit of mining–flotation–hydrometallurgical processing of flotation concentrate; silver—61.3% and gold—64.3%. Furthermore, more valuable metals can be additionally extracted after secondary treatment by the injection-and-blasting.

3. Conclusions

In the rockbursting conditions of deep-level mining in the Darasun and Teremki deposits composed of gold–sulphide–quartz loads, efficient modes and parameters were experimentally determined for in-situ leaching of gold with the injection-and-blasting pretreatment of ore blocks. The chemical preparation process was modeled as blasting with injections of peroxide–chloride solutions in the cemented mill tailings using propellant charges. After such preparation, the block was subjected to leaching by active chloride–peroxide solutions in the pulse static mode. The final gold recovery totaled 80% in three days.

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