

Substandard Ore Reserves Development Efficiency by Leaching Technologies

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Abstract: The study is devoted to the issue of currently inactive metal deposit reserve introduction into production. The research of underground metal block leaching technology with the preparation according to the traditional scheme determined that the traditional preparation of PV units is ineffective. It is reasonable to carry out leaching on the basis of a solid non-pillar scheme which reduces the amount of preparatory solid works. The methods of technology development determination effectiveness by comparing the index a useful component complete extraction from the depths by the traditional and the combined method. The importance of leaching mountain aspect research is determined for the implementation of the mining production tasks.

Key words: Stocks, metal, deposit, research, technology, leaching, preparation, efficiency

INTRODUCTION

The global integration processes with an increased competition for survival is accompanied by the cessation of low-profit or subsidized mining enterprise activity. In an effort to maintain the economic viability the selective development of the richest deposit areas is activated with the transfer of the significant part of stocks into the category of inactive ones (Dubinski, 2013).

At the same time, the stocks of many deposits, sub-standard for the traditional methods of metal production are conditional ones for the ways with metal leaching. These are, for example, the deposits of the Northern Caucasus: Sadonskoe, Tynny-Auzskoe, Urupskoye deposit and their analogues in Russia and abroad. Under certain conditions, their development may be profitable at the use of metal extraction combined methods.

Now a days the involvement of written off reserves in production has not only an economic value but also a strategic value as it serves the strengthening of the mineral resource base and the national security of states as rare earth metals are extracted additionally during leaching process.

A real opportunity of mineral resource engagement in production is provided by the technologies with the

leaching of metals from ores underground and on the surface but the duration of cost recovery processes prevents the expansion of these technologies application, although the half of produced metals is obtained during mining by leaching at a large Russian enterprise Priargunsky mining and chemical plant (Morozov *et al.*, 2013).

Mineral Underground Leaching (UL) technology in the place of their occurrence has certain distinctive features: the preparation of a block involves the tunneling of special irrigation and drainage patterns the size of a rock mass is the priority factor. The experience of an underground block leaching of metals is accumulated at the mining enterprises of Northern Kazakhstan and Baikal region (Lyashenko, 2001; Lizunkin *et al.*, 2013; Svyatetsky *et al.*, 2012).

MATERIALS AND METHODS

The leaching efficiency is determined by a complex method, including the assessment of ore crushing quality and the completeness of metal extraction. To do this, the control mining is performed with the selection of samples after the leaching of ore within leaching tails. The difference between the initial and the final metal content in ore is determined by the completeness of metal

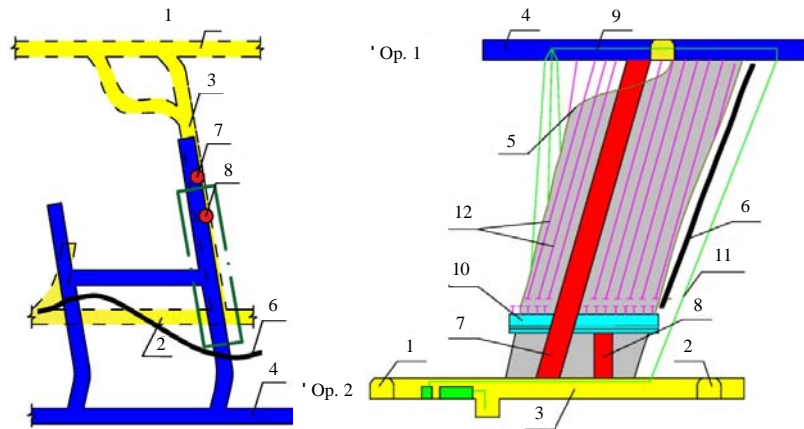


Fig. 1: Test block preparation: 1, 2: drifts; 3,4: ports; 5: an ore body boundary; 6: break; 7: cut raise; 8: box hole; 9: mounting layer; 10: undercut layer; 11: the well for solution supply; 12: blast holes

extraction for ore fractions. Balance reserves were mined at the deposit of Northern Kazakhstan, folded by lenticular ore body in split-off sedimentary rocks with the strength of 4-6 according to Professor Protodyakonov's scale (Golik, 2014) in a test block 1 (Fig. 1).

The cutting works in a block included the formation of a mounting and a slash layer, the conduction of an exhaust box hole, a cut raise and a cutting gap. A mounting layer was a top undercutting for blast hole drilling and an irrigation system placement. An undercut layer was conducted with the slope of 5° to the block center. PVC film covered the bottom area of the block for waterproofing. The block parameters were the following ones: length 23-27 m, width 5 m, height 28 m (Fig. 1).

The machine NKR-100M drilled 44 parallel holes along the grid of 1.7×2 m with the slope along an ore body with the shortage of drilling by 1.5 m. The loading of wells was carried out by the granulite AC-0. Blasting was performed by electric method according to an opposition circuit, a short-delayed one with the delay interval of 25 sec between the rows. The total charge weight made 4200 kg. The loosening coefficient made 1,12. The leaching lasted for 6.5 months to reduce the PK concentration to the level which did not meet the requirements.

To determine the leaching completeness the block was opened in 4 substages by minings with the section of 6-8 m² along leaching tails with fastening. It was found that the cutting slot area experienced the compaction of ore. In some places the ore particle size reached 1.2 m, the desired crushing of the massif occurred only in the region equal to 2-3 diameters of a charge the solutions were moved along overgrinding ore in the footwall area.

The process intensification was carried out by the charges in the wells the diameter of which made 85 mm and 65 mm with the mesh increase by 2 times. The loading of wells was performed by the Granulite AC-4. The 35 wells with the diameter of 105 mm and 15 wells with the diameter of 65 mm were exploded on the 1-st substage. The ore of the substage 2 was crushed substage by 3 charges from the box hole raise in the wells with the diameter of 65 mm. The compensation space was formed by fine hole method. The total number of wells made 42 (7 fans, each fan contained 6 wells). The repeated crushing was performed at the substage III using 73 wells. The total quantity of explosives for re-crushing made 5120 kg and it provided the loosening ratio of 1.43. The amount of metals was produced 1.22 times more than during the first leaching stage within 4.5 months after the intensification.

Block 2 was laid in the sidewall of the ore deposit with the following parameters: length-60 m, width-10-26 m, height-36. The capture of productive solutions was carried out by the drainage roadway along wells. The irrigation system was equipped on the surface of the ore left in store. The roof of the irrigation horizon was supported by lining. The rising wells with the diameter of 85 mm were used during ore crushing. Blasting was carried out with the deceleration of 25, 30, 75 and 100 msec.

The parameters of drilling and blasting works in the block 2: the line of least resistance made 2.6 m; the distance between the ends of the wells made 2 m; the charge convergence coefficient made 0.97, the well length made 9.5 m the consumption of explosives made 1.3 kg/m³; the production of ore from 1 m of wells made 3.9 m³/m; the ratio of well use 0.8; loosening coefficient made 1.23; BB type grammonite 79/21, ammonal BA8.

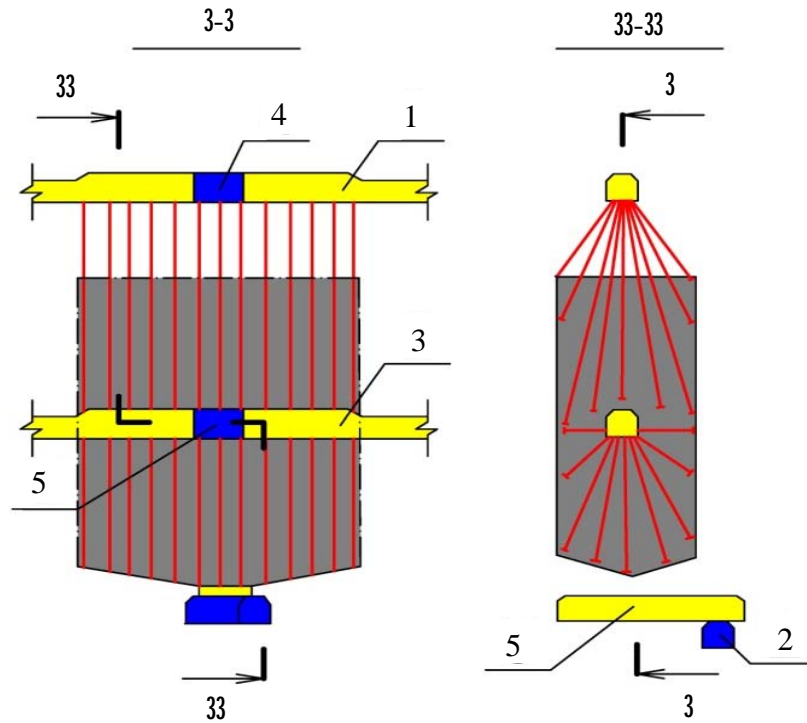


Fig. 2: Block preparation for leaching with the combination of mining functions: 1: irrigation-drilling drift; 2: lower storey drift; 3: drill drift; 4: upper box-hole raise of a slot; 5: lower box-hole raise of a slot; 6: the split

The penetration of test excavations found out: an oversized class output was three times more than these evaluations of ore crushing by photo plane geometry method; the area between the drill drifts was crushed unsatisfactory; the areas overgrinding ore and increased filtration areas were formed.

Experimental works determined that the traditional preparation of blocks for PV was ineffective. It is reasonable to carry out leaching on the basis of a solid non-pillar scheme that will reduce the amount of preparatory cutting works, for example, the variant with a stage upholstery of ore (Fig. 2).

The labor complexity decreased more than twice, the share of cutting works decreased 3 times and the efficiency of mining and preparatory works increased 2.5 times.

The duration and the completeness of metal extraction from ores depend on ore crushing degree and also on a uniform placement of ore, providing the wetting without nonirrigated zones (Petersen, 2015; Sinclair and Thompson, 2015). At the breaking of ore by vertical layers with the partial release the zones are developed with different loosening coefficient. This disadvantage is eliminated by forming a compensation space inside each

crushed volume. The breaking is performed using a horizontal undercutting by stages, bottom-up with the advance of an undercutting during the crushing of layers at the thickness of a crushed vertical layer (Fig. 3).

This method allows to form the environment of equal density in a block to improve fragmentation to reduce the amount of preparation cutting operations and reduce the cost of products by 25% as compared to the reference method.

The laboratory studies determined that at the same size of ore (-350 +0 mm) the extraction process speed is reduced due on the lower portions due to concentration gradient decrease between the pore solution and the solvent volume. If an ore layer height makes 10 m, the reagent concentration in a working solution makes 15 g/L and a continuous irrigation the extraction makes 59% in 300 days. Under the same conditions but with different size of ore along a layer height they extract 59% in 260 days.

The effectiveness of mining technology combination is estimated by the comparison of a Useful Component (UC) extraction completeness from the depths by Traditional (TS) and combined production method (Bradl, 2004; Gupta and Krishnamurthy, 2005).

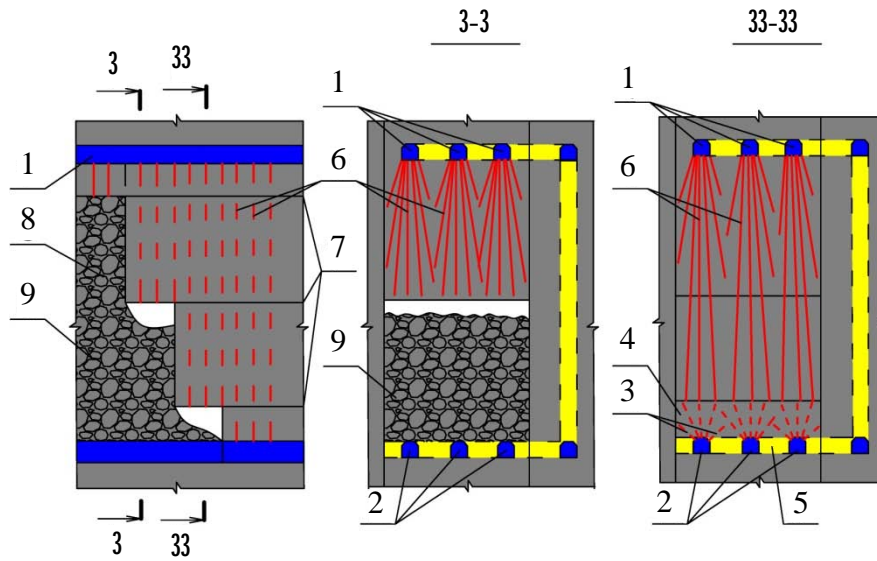


Fig. 3: The formation of compensating space inside the breaking volume: 1: the workings of an irrigation horizon; 2: the workings of solution capture horizon; 3: rising holes; 4: the undercut level; 5: the broken ore; 6: the downward holes; 7: the section boundaries; 8: the stored ore; 9: the ore which needs additional crushing

RESULTS AND DISCUSSION

The traditional way of mining differs by ore production with the balance content of metals. The amount of produced PK (M_1):

$$M_1 = Q_6 \beta_6 \epsilon_1$$

Where:

- Q_6 = The amount of ore in the balance circuit, mass, un
- β_6 = PK content in the balance circuit, units
- ϵ_1 = PK recovery factor, un. PK amount (M_2), extracted in concentrate

$$M_2 = M_1 \epsilon_2 = Q_6 \beta_6 \epsilon_1 \epsilon_2$$

where, ϵ_2 PK recovery ratio from mined ore into the concentrate. The amount of PK recovered from the concentrate into a final product:

$$M_3 = M_2 \epsilon_3 = Q_6 \beta_6 \epsilon_1 \epsilon_2 \epsilon_3$$

where, ϵ_3 PK recovery ratio from the concentrate into the final product. PK extraction completeness (ϵ_3) is the ratio of PK in a final product to the amount of PK in the depths:

$$\epsilon_3 = M_3 / M = (Q_6 \beta_6 \epsilon_1 \epsilon_2 \epsilon_3) / M$$

$$M = M_6 / M \epsilon_1 \epsilon_2 \epsilon_3$$

Where:

- M = The amount of PK in the depths prior to development
- M_6 = The amount of PK in a balance circuit

Combined method includes the issue of ore portion from a block, its enrichment, the extraction of useful components from shranked ores and at a factory. The number of PK (M_4), extracted from the subsoil:

$$M_4 = Q_b \epsilon_b$$

Where:

- Q_b = The amount of produced ore
- ϵ_b = PK content in produced ore

PK amount (M_5), extracted into the concentrate:

$$M_5 = M_4 \epsilon_2 = Q_b \beta_b \epsilon_2$$

PK amount (M_6), extracted from the concentrate into a final product:

$$M_6 = M_5 \epsilon_3 = Q_b \beta_b \epsilon_2 \epsilon_3$$

The PK amount (M_7), extracted into a final product by leaching, it is the difference between the possible amount and an actual one extracted from the subsurface:

$$M_7 = (M - M_4) \varepsilon_4$$

$$(M - Q_B \beta_B) \varepsilon_4$$

where, ε_4 PK extraction ratio from the ore at PV, un. The total amount of PK (M_k), extracted into a final product at a combined development:

$$M_k = M_6 + M_7$$

Throughout recovery of PK from the depths into the final product ε_k :

$$\varepsilon_k = (M_B + M_7) / M = [(Q_B \beta_B \varepsilon_2 \varepsilon_3) + (M - Q_B \beta_B) \varepsilon_4] / M = [(Q_B \beta_B \varepsilon_2 \varepsilon_3) + (M \varepsilon_4) - (Q_B \beta_B \varepsilon_4)] / M = \varepsilon_4$$

$$[\varepsilon_4 + Q_B \beta_B (\varepsilon_2 \varepsilon_3 - \varepsilon_4)] / M = \varepsilon_4 + M_4 / M (\varepsilon_2 \varepsilon_3 - \varepsilon_4)$$

The PK recovery completeness is described by the following dependencies:

- For traditional technology: $\varepsilon_m = k M_6 / M \varepsilon_1$
- For combined method: $\varepsilon_k = \varepsilon_4 + M_4 / M (k - \varepsilon_4)$

where, $k = \varepsilon_2 \varepsilon_3$ constant value for certain ores and the technologies of their processing. The PK losses are estimated at the comparison of alternative techniques which differ by the completeness of metal extraction from the depths. The estimation of losses according to PK lost value allows you to use the criterion of profit, taking into account the damage from PK losses:

$$\varepsilon_k = (M_B + M_7) / M = [(Q_B \beta_B \varepsilon_2 \varepsilon_3) + (M - Q_B \beta_B) \varepsilon_4] / M$$

$$M = [(Q_B \beta_B \varepsilon_2 \varepsilon_3) + (M \varepsilon_4) - (Q_B \beta_B \varepsilon_4)] / \varepsilon_k$$

$$M = \varepsilon_4 [\varepsilon_4 + Q_B \beta_B (\varepsilon_2 \varepsilon_3 - \varepsilon_4)] / \varepsilon_k$$

$$M = \varepsilon_4 + M_4 / M (\varepsilon_2 \varepsilon_3 - \varepsilon_4)$$

Where:

- Π = Profit
- M_u = The element extracted into the final PK product
- M_n = Lost PK
- Π_n = Marginal industry price per PK unit in a final product
- z = Processing costs

Since, not only balance PV and KV are practiced but also off-balance reserves the lost value of traditional technologies should be increased by the value of lost reserves (Akciil, 2002; Golik *et al.*, 2015; Golik, 2014).

At the issue of rich ores for the compensation of explosive loosening of ores 40% it contains no <50% of metal reserves and the metal content is increased 1.2 times as compared to the average one in a block.

At the factory processing of ore the coefficient of metal extraction varies by 8-10%. The reduction of extracted ore quality by traditional technology increases the loss of metal at a factory by 1-2% due to dilution. At the use of technologies with the leaching the losses are eliminated due to dilution, thus, the recovery ratio is increased by 1-1.5%. The technology with leaching reduces the loss of metals during production by 5.10% and by 2-2.5% during enrichment as compared to the conventional technology.

The throughout recovery ratio in conventional technology does not exceed 0.865 under equal conditions, and 40.5% of PK will be recovered with the extraction coefficient 0.930 for PV method at the issuance of 40% with 50% of metal content in HMP.

From remained 50% of balance metal reserves at PV extraction coefficient of 0.8 and subject to PK losses during solution processing 39.2% of metals will be obtained in a final product. At 3% of metals in off-balance ores 2.3% of PK will be recovered from them in a final product. The throughout coefficient of PV metal extraction makes 0.879. The maximum efficiency of mining is provided by enhancing the recovery of useful components from the depths:

$$M' \geq \frac{\varepsilon_n - \varepsilon_T}{\varepsilon_n - \varepsilon_2 \varepsilon_3} \times M$$

Where:

- M = The amount of useful component in the depths
- M' = The amount of useful component, produced from the depths
- ε_n = The extraction of metals from ores by leaching technologies
- ε_T = The extraction of metals from at its mining by TS

$$\varepsilon_T = \frac{M_3}{M} \times \varepsilon_1 \varepsilon_2 \varepsilon_3$$

Where:

- M_B = The amount of TS metals
- ε_1 = The extraction of metals from TS depths
- ε_2 = The extraction of metals in the concentrate
- ε_3 = The extraction of a useful component from the concentrate into a final product

The profit from the involvement of natural and man-made resources in production in the form of off-grade ores are described by the following mathematical economic model:

$$\Pi_{pr} = A_t (\Pi_{nt} - C_{nt}) = nt \left[\Pi_{prt} \frac{1}{(1 + E_{nt})} - K_{ct} (1 + E_{nt}) \right]$$

Where:

- Π_{pr} = Profit
- A_t = The annual production capacity of an enterprise by using the sub-standard ores in t-th year
- Π_{prt} = Annual profit
- nt = The amount of years of use
- \prod_{nt} = Production costs in t-th year
- C_{nt} = Production costs in t-th year
- K_{ct} = Annual upgrade costs in t-th year, rub
- E_{nt} = The coefficient which takes into account the interest rate on the loan to carry out the preparatory works in t-th year

The efficiency of technologies (P) is determined by the total amount of value involved in resource production:

$$P = \sum_{i=1}^n Q_i \Pi_i = Q_p (\Pi_x - c_x) - Q_3 \Pi_3 - Q_n \Pi_n - Q_B \Pi_B$$

Where:

- Q_i = The value of i-th resource
- Q_p = Stock reserves
- n = Types of resources
- \prod_i = The value of i-th resource unit
- $Q_3 Q_n Q_B$ = The resources of lands, rocks and water deteriorated by an enterprise
- \prod_x = Production costs
- C_x = The value of products

CONCLUSION

The deficit of metals for the industrial needs will be increased. The economy reserve is the involvement of sub-standard resources in production through the use of metal leaching technologies which are reasonable to combine with traditional development technologies.

An optimal value of indicators is achieved most often when a smaller part of an ore is given to a surface and much of the ore is leached underground. At that the productivity of metal in a final product is several times higher than at the conventional process with the same performance according to rock mass. The throughout recovery factor at the combined technology is comparable to the extraction during the traditional technology and the minimization of costs allows you to make a profit.

The solution of complex and complete development of depth is contributed by the development of continuous production technology concerning the leaching of valuable components from metal ores. The study of mining aspects of leaching and the development of scientific bases and the ways of its implementation are the major tasks of mining production.

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