New resource-saving technologies for gold recovery from rebellious and hard-to-process material of clayey deposits and mining waste

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Abstract. It is proposed to make leaching piles by layering of crushed fractions by size grades from the bottom layer upward at certain orientation of the pile relative cardinal points and with spraying under waterproof and solution-impermeable light transmissive film. The combination gravity–electrochemical processing technology is proposed for gold extraction from dredge and sluice tailings, and the complete processing line is designed for all-year-round operation, including low-temperature conditions, based on pretreatment of polycomponent chlorine leaching solutions by electrochemical and photochemical synthesis. The magnetic flocculation add-on device is developed for fitting sluices and meant to reduce fine gold loss. The paper presents new engineering solutions that enable higher efficiency and intensity of gold extraction from clayey materials and mining waste, as well as integrated use of natural resources.

1. Introduction
Nonferrous metallurgy in Russia is poorly supplied with raw materials, especially, uranium–copper–gold–manganese–aluminum–nickel-bearing ore [1–3]. At the present time, in view of the lack of large investment in the resource sector of Russia, for production of critical metals, it is urgent to find new technologies for processing uneconomic ore and accumulated old waste of earlier mining and processing operations, as well as clayey gold-containing sand with high content of useful component. Mining companies nowadays tend to reduce financial expenses and risks, they mostly place money in projects with modest capital investment.

The analysis of advancement in technology and equipment for gold recovery from waste and clayey gold-bearing sand in Russia and abroad shows that the top-priority objectives in this regard are reduction in loss of valuable component and improvement of recovery efficiency of fine and very fine gold particles. To meet these objectives, it is required to use in a big way innovative engineering solutions [4–8].

2. Intensification of gold recovery
Being proposed for intensification of gold recovery from uneconomic ore and to improve profitability of mining companies, some engineering solutions have increased valuable component extraction by 5–
10% in heap leaching owing to elimination of pore space mudding due to segregation of ore lumps at the pile bottom and by suffusion (Figure 1) [9].

Uneconomic ore is separated on screening-and-crushing plant into size grades of –5.0, +5...–10, +10...–15 and +15...–20 mm, as a rule. Piling of crushed fractionated ore is carried out by layers, with size grades decreasing from bottom upward, i.e. stock pile layer 1 is composed of size grade +15÷–20 mm, the overlying layer is made of smaller size grade +10÷–15 mm and so on up to the upper layer 2 filled with the finest particles –5.0 mm in size.

Figure 1. Heap leaching stock pile: (a) elevation view (1—bottom layer particles +15...–20 mm; 2—upper layer fraction –5 mm; 3—spraying and saturation system; 4—side surfaces of stock pile; 5—process solution collectors; 6—stock pile understructure; 7—perforated polymeric film; 8—support arcs; 9—waterproof and solution-impermeable light-transmissive film; 10—thermal insulator; (b) top view.

Sloped layering of fractionated ore interlayered with perforated polymeric film prevents outflow (washing-out) of clayey and slime particles. Fine particles flow along an inclined layer toward the side surface of the pile, which creates favorable conditions for uniform penetration of solution to the lower-lying layers, and leaching efficiency and completeness of metal extraction to pregnant solution is increased by 10% as a result.

Stockpiling with its wider part oriented to the south and spraying under waterproof and solution-impermeable light transmissive film make it possible to increase the solution temperature by means of absorption of solar radiation and to totally eliminate energy loss in evaporation and to partly reduce energy loss in convective exchange with outer air. The temperature increase is governed by the season, time of day, solar radiation intensity and climatic factors, and is from 5 to 15°C.

Analyzing zoning map of permafrost area of Russia and arrangement of metallogenic belts, it is seen that the key resources of gold mining locate in the Arctic and Subarctic zones, and nearby their southern periphery.

The limiting factors of efficient application of innovations in heap gold leaching in Transbaikalia are: occurrence of most small gold deposits in the areas of frozen and permafrost rocks; complex polycponent composition of valuable elements and harmful admixtures, as well as elevated content of toxic and potentially toxic components; specific development of temperature inversions in deep ravines and depressions of the Baikal type; little snow falling in winter with clear trend of snow cover redistribution in some regions of the permafrost zone in East Transbaikalia [10].

Much gold is also concentrated in dredge and sluice tailings, intrinsically, fines and flakes, floured gold, or super fine impregnations in ferrous oxides and placer sulphides. The problem of processing of such material consists in the presence of gold within particulate range of 0.07 + 0.05 mm.

The processing technology for dredge and sluice tailings at gold placers in Transbaikalia was tested on semi-commercial scale. The testing included gravity separation on deep filling gateways with concentrate production (magnetite fraction, $\beta_{Au} = 0.75 \text{ g/m}^3$, iron oxides FeO·Fe$_2$O$_3$); first-stage dish
leaching by highly active hypochloric acid obtained in electrochemical and photochemical synthesis; second-stage heal leaching by cyanides. The absolute recovery of gold from waste was 95%. The complete processing line ensuring all-year-round operation, including under low temperature, was also developed [9].

Production and processing of gold-bearing clayey sand uses, as a rule, digging machines connected with washing–haulage–transportation systems; therefore the continuity and close interrelationship of all processes predefines improvement of the processing circuit. The loss of valuable component in tailings depends, for the first turn, on efficiency of disintegration and washing of clayey sand, as well as on upgrading of classical and nonconventional equipment for extraction of fine and very fine grades of valuable component [11].

The process operations subject to further improvement include:
—intensive disintegration of difficult clayey sand and removal of cementing clay in the beginning of processing;
—improved efficiency of recovery of fine and very fine gold in separators;
—development of detailed process flow charts for recovery of rebellious fine, very fine and floating gold.

Regarding enclosing nonmetallic material of gold sand, it is recommended:
—to use chiesley rocks after gold-bearing sand washing in other industries (road construction, etc.);
—directional sedimentation of silt-loam particles for making pellets for heap gold leaching and application in other industries (construction).

Within recent years, the team of young researchers of the Chita Division of the Institute of Mining, SB RAS, and Transbaikalia State University has developed and patented complete clayey sand processing lines capable to reduce free gold grains—plate fines, small and large grains with cementing clay. This provides integrated use of mineral raw materials, including enclosing nometallic component (silt–loam settlings and chiesley gangue) in various branches of industry, for instance, in construction and mining.

In the complete processing lines for gold-bearing sand, the scrubbing and sorting machines ensure intensive disintegration of hard-to-wash materials at the head end of the process and to put out the floating gold-containing flow via a spiral classifier discharge and an earth trench for subsequent extraction of floating gold in a special physicochemical module. Then, fine gold is extracted from the pre-washed sluicing tailings on sluices connected with magnetic flocculation add-on device equipped along the length of the chute with alternating polarity magnets made of neodymium–iron–boron alloy. This engineering solution allows holding fine gold in the mass flow by “magnetic fur” formed by floccules of magnetic and strong magnetic particles. The magnetic flocculation add-on device is fitted with a system of frequent rinsing of concentrate, which increases productive fraction yield and reduces labor-to-output ratio of the process. In the sedimentation structure, by direction physicochemical flocculation, suspended particles in process water are settled and subsequently used as construction materials or anti-seepage filler in the bodies of retaining dams. Furthermore, this clayey product can be used as a binder in agglomeration of mineral raw material in heap leaching. Clarified top layer is returned to the processing circuit, and tailings of concentrate finishing are forwarded to primary concentrate processing plants for separation and utilization later on [11].

3. Conclusions
Thus, new technologies of gold recovery from rebellious and hard-to-process clayey materials and waste will reduce process loss of gold and make it possible to utilize mineral reserves for multiple purposes [9–11].

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