Improvement of technologies and technical means for ore mining and processing industry

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Abstract
Objective is improvement of technologies and technical means for mining and processing industry on the basis of taking into account of functional subsystems, as well as their purpose and the main characteristics of the automated system when ore processing.
Methodology consists in analysis of literature sources, methods of theoretical generalizations of physical properties of ores, device development, physical and mathematical modeling, as well as laboratory research and industrial implementation using conventional and standard techniques.
The main *scientific and practical results* of improvement of technologies and technical means for mining-and-concentrating industry are shown using the example of deposits with a complex structure which have been developed by experts of the industry and leading scientific centers of the Russian Federation, Ukraine, Kazakhstan, and other CIS countries. The modern mineral and raw materials base of CJSC Vasilievsky Rudnik and main organizational and technological measures to increase its efficiency for the base of some companies are described. The issues of concentrating and processing of extracted gold ores, organizational measures for CJSC Vasilievsky Rudnik (Russian Federation) aimed at increasing the efficiency of production at these process stages are considered.
*Scientific novelty***.** A new system of head sampling at the gold recovery plant was developed and introduced, which allowed improving sharply the reliability of the results, reduce labor costs and decrease of the number of samples processing by the laboratory from this operation by 6 times.
Practical significance. Measures increasing the efficiency of the gold recovery plant, technological sampling maps, new designs of crushers and mills, which allowed us to increase the efficiency of crushing and grinding of open grains of gangue depending on the deposits of useful minerals were proposed. The results of preliminary studies on the concentration of oxidized quartzites (Krivbass, Krivoy Rog, Ukraine) have shown the possibility of obtaining concentrates with a mass fraction of iron to 60.6% with a recovery level of 76.9%. The mass fraction of iron in the tailings is 14.
Key words: ORE, CONCENTRATING PRODUCTION, PROCESSING, TECHNOLOGIES AND TECHNICAL MEANS, EFFICIENCY INCREASE

Introduction

In the national economy, the crushing and grinding of ores and other solid materials are one of the most large-scale, energy-intensive and costly operations. More than 3 billion tons of mineral raw materials and other materials are annually grinded and crushed. For this purpose, more than 70 billion kW·h of electricity is spent or up to 5% of its total production. More than 4 million tons of metal or more than 2.5% of its production are consumed on grinding bodies and lining of working parts of the units. In the concentrating factories, 50-70% of the total capital costs and the same share of total operating costs are accounted for operations of crushing and grinding. According to some estimates, only in the US, the annual electricity consumption for the disintegration of mining raw materials is about 32 billion kW·h, most of which is spent on fine grinding. These processes are used to bring mineral raw materials (and other materials) to the required size, the required grain size composition or a given degree of disclosure of minerals.

The preparatory concentrating processes associated with the reduction in the size of the material are the most resource intensive. At that, grinding accounts for more than half of all operating costs when processing the initial ore in concentrate. Existing systems for optimizing the process of ore grinding in tumbling mills based on the use of signals of the average active power of the engine or the noise of the mill are often ineffective due to the weak connection of these parameters with the process of breaking lumps of ore in the shell.

Therefore, the improvement of technologies and technical means for ore mining and processing production based on the considering of functional subsystems, as well as their designation and the main characteristics of the automated system when ore processing, is an important scientific, technical and practical task requiring immediate solution [1-5]

To solve given problem, the authors used a complex method including analysis of literature sources, methods of theoretical generalizations of physical properties of ores, device development, physical and mathematical modeling, as well as laboratory research and industrial implementation using conventional and standard techniques.

Discussion and evaluation of research results

The list of functional subsystems, as well as their purpose and the main characteristics of the considered automated system when processing gold ores include the following:

- at the grinding area and transferred to the ore processing shop of the ore preparation of input mineral raw material by weight;

- in the shop of ore preparation of the taken and processed gold ore at the grinding stage and classification by weight and content of gold in the pulp (the function of maintaining the necessary ratio of solid to liquid (S:L) and grinding fineness of gold ore);

- on the gravitational processing stage of taken and processed pulp by weight and content of gold in it (the presence of functions for dispensing special reagents, as well as maintaining the required level of industrial products);

- taken and processed gold-containing concentrate by weight and gold content in the pulp (availability of dispenser functions);

- accepted for the regeneration of saturated resin from the area of sorption and commercial accounting of commodity regenerate and anode solutions by weight and the content of gold in them (the presence of functions for determining the necessary concentration of cyanides, maintaining the proper alkalinity and acidity, adjusting the necessary pH value and the stored level in columns of gold desorption and resin regeneration);

- accepted for disposal sorption processed tailings by weight and gold content (the presence of dispenser functions of lime milk and sodium hypochlorite in order to maintain the set pH and the residual concentration of cyanides in the tailings that are thrown off).

CJSC Vasilievsky Rudnik (Russian Federation)

Possession of mineral reserves that provide quite cost-effective production of gold in existing production areas has a fairly valid perspective of high growth potential in the coming years. Based on the existing mining and geological conditions of deposits and technological properties of gold ores belonging to the Vasilievsky Rudnik, the most promising option seems to be the continuation of their factory processing and the parallel development of heap leaching together with other development projects (Fig. 1). The results of a number of current geological and technological researches, as well as experimental works for the production of gold will be in demand only after 5 years or more. Therefore, it is advisable to revise the terms and, accordingly, the costs of geological exploration works (GEW), research and development works (R&D) and design and survey works (D&S) based on the actual needs of the enterprise (including plans to bring the processing of gold ore at the gold recovery plant to 600 thousand tons per year).

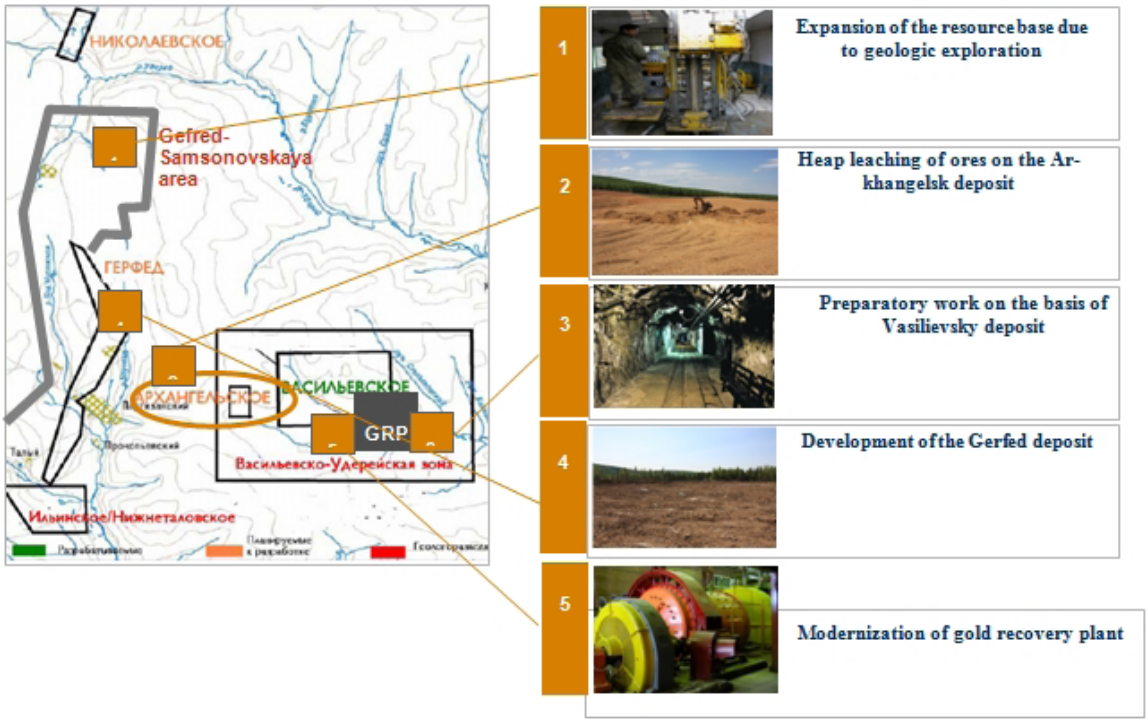


Figure 1. Prospective projects of CJSC "Vasilievsky Rudnik": 1- identification of the most prospective areas and exploration; 2 - completion of construction and output to design capacity, 3,4 - additional exploration, development of design estimates, construction and start-up of production at the Vasilievsky and Gerferd deposits, respectively, 5 - reconstruction of the crushing department, expansion of the gravity and cyanidation shops

A set of measures was developed and justified to prioritize the development of the raw materials base and to increase the level of predictability of reserves providing a detailed analysis of the Company's available mineral reserves and the period of their possible development. There is a certain practice that a mining enterprise should be provided with reserves at a level no less than the recoupment of capital expenditures necessary to develop existing reserves [6]. It is also necessary to take into account the costs of maintaining production and equipment updating. Usually, it takes at least 8 years to pay back such costs. With a longer reserves life, as a rule, capital expenditures are justified (unless there are serious problems with mining, geological and technological conditions).

When considering the issues of concentration and processing of extracted gold ores, the organizational arrangements for CJSC "Vasilievsky Rudnik" aimed at improving the production efficiency at these stages were grouped by us in accordance with the main processes (Fig. 2). The company CJSC "Vasilievsky Rudnik" was built according to the technological scheme developed by JSC "IRGIREDMET" (Irkutsk, Russian Federation) with the use of hardware design of 70-80s of the last century. Therefore, in this factory, at the present time, the system of modern automation of basic production processes is practically completely absent, which sharply increases the negative influence of the "human factor" reducing the already low (in relation to modern equipment) performance indicators and quality of the carried out concentration processes. As a result, the current level of gold extraction at the processed ores at the CJSC "Vasilievsky Rudnik" is extremely low (30-35%) compared to its extraction at known similar plants.

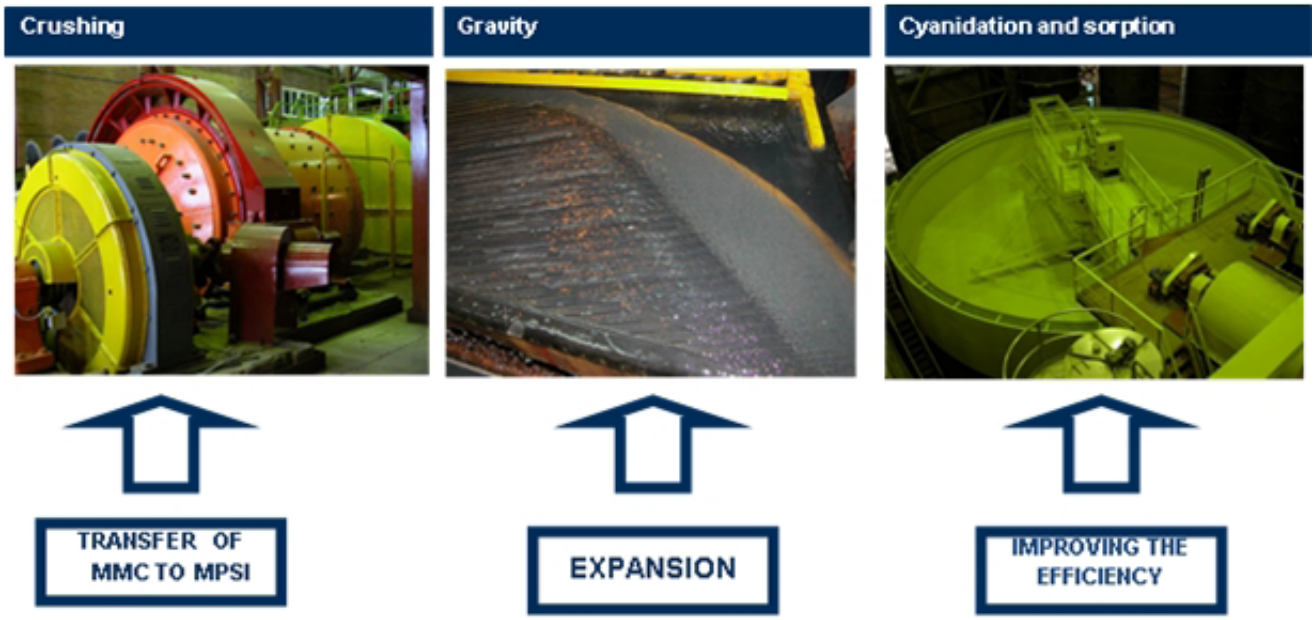
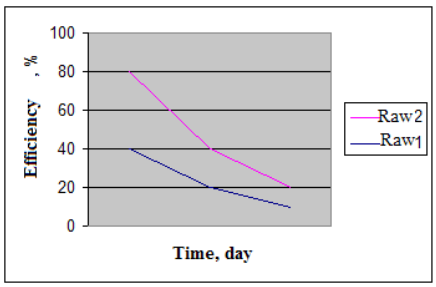
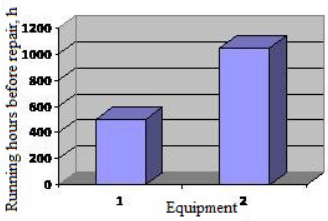
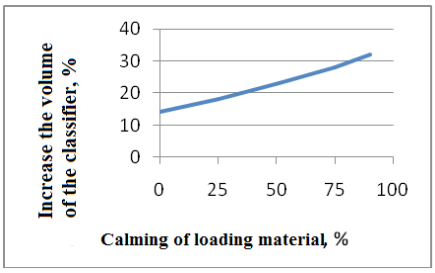
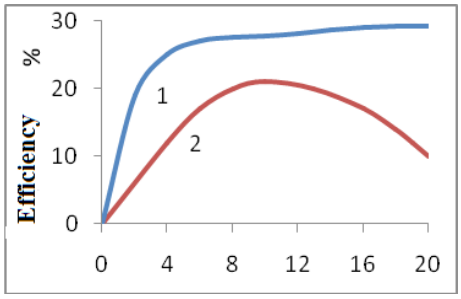
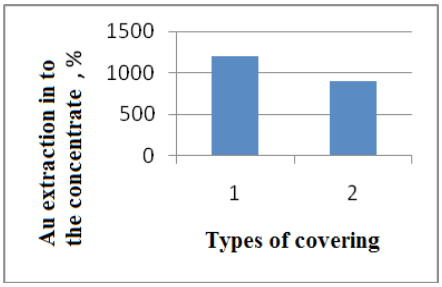
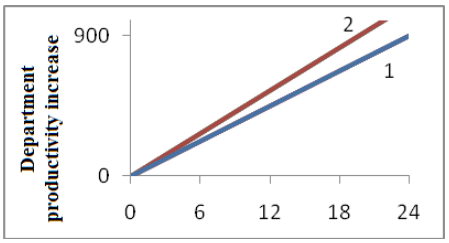
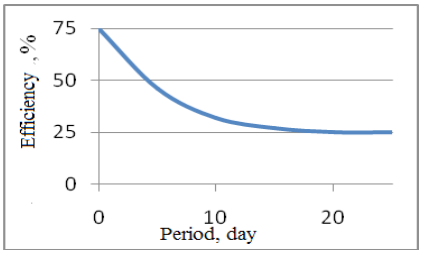
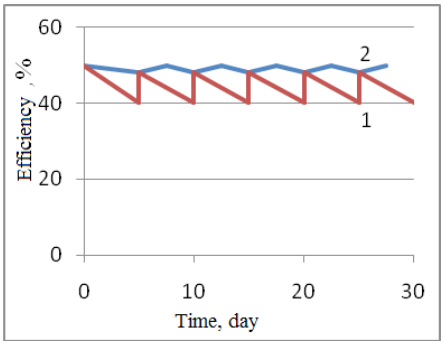
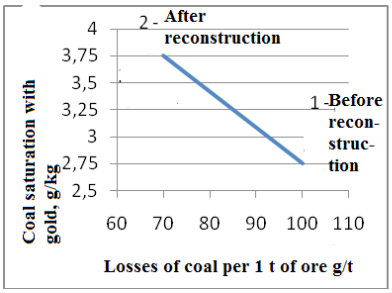
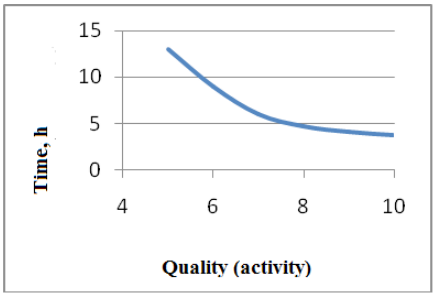


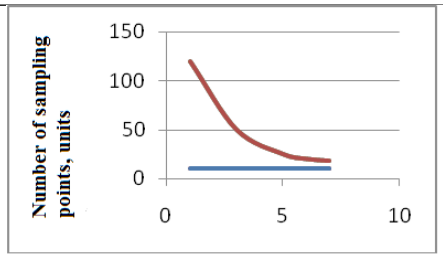
Figure 2. Picture of the gold recovery plant departments

Analysis of possible organizational measures to increase the processing efficiency of gold ores at gold recovery plant CJSC "Vasilievsky Rudnik" (Table 1) has shown that optimization of work, separation of crushing and shredding (at a design capacity of up to 900 tons of gold ore per day) allow obtaining a finished class yield of up to 90%. The carried out experimental-industrial studies have shown almost a direct dependence of the degree of gold extraction from the quality of grinding the gold ore. Thus, the highest figures are achieved when the output of the finished class is equal to 94 - 96%. It was found that the value of the productivity of ball mills and the efficiency of grinding ores to a greater extent depends on the amount of ball load and its quality. The lack of balls or their incorrectly sized dimension significantly reduces the specific productivity of mills and the quality of gold ores crushing [7].

Table 1. Measures that increase the efficiency of the gold recovery plant

Shop	Unit (equipment), technology	Organizational measure	Effectiveness of the measure
Department of crushing and grinding	Ore crushing	Optimizing the dimensions and the ratio of the balls of mill	 1,2 - balls with a diameter of 60 and 40 mm, respectively;
	The "pump-hydrocyclone" system	Classification of pulp	 1 - sand pump; 2 - pump-hydrocyclone system
	Classification on spiral classifiers	Increase in the working volume of the classifier	
Department of gravity	Jigging machines	Timely repairs, availability of spare parts, replacement of cars for more modern ones	 Extraction of gold from the duration of the jigging machine: 1,2 - in full compliance with the technical regulations and with a lag behind it, respectively
	Concentration tables SKO type	Compliance with the coating requirement	 1,2 –the recommended and "up-to-date" coating, respectively

	Centrifugal concentrators	Introduction of Knelson concentrators with parallel installation of the cyanidation reactor	 Period of time: 1 - in the absence of settings; 2 - using the settings
	Mill of re-grinding of the gravity tailings	Application of cilpubs as grinding bodies	
Department of thickening	Thickening technology	Introduction of process automation	 1,2 - manual and automatic adjustment, respectively
Department of cyanidation and sorption	Pulsating columns	Reconstruction of column headers, automation of cyanide feed	 Reconstruction of column headers
Department of reagents preparation	Quality of used lime	Use lime with the necessary activity	 Dependence of processing time on the quality of lime milk

Sampling center	Sampling technology	Automate the sampling process	 The sampling process: 1 - manual mode, 2 - automatic mode, 3 - curve determined by the number of sampling points (manual mode), 4 - curve determined by the number of sampling points (automatic mode). Dependence of the sampling duration at the gold recovery plant from the system and the number of sampling points

The use of grinding balls ***d*** = 100 mm in the first stage of grinding of gold-bearing ores is very promising, as a result of which, there is an additional opportunity to increase the productivity of the mills in the initial ore by 30 t/h [8]. In the second stage of grinding of gold ores, the use of balls with a diameter of 60 mm and smaller is recommended since in this case the main effect is achieved primarily by abrasion of the processed gold ore material (minerals). Experimental and industrial work was also carried out to test the grinding on the changed size of the balls. The result of this experiment was an increase in the efficiency of the plant from 1000 tons of ore to 1100-1400 tons per day. At the same time, for 3 months of testing, the output of the finished class has been increased by an average of 1.5%, which allows additionally extracting 1948 grams of gold into the ingot during this period. In addition, operative management of the quality of gold ore grinding is carried out by changing the productivity of ore (based on a special adjustment of vibration feeders), changing the amount of water (fed to mill washing trommels and pump sumps), and timely loading of balls into mills and regular replacement of wear sands liners of hydrocyclones. It is also necessary to control the quantitative indicators for the tonnage of grinding of gold ore (by means of automatic granulometers), hydrocyclones overflow with a size of 85-88% of the class -0.074 mm with a content of solid of 25-27%. High performance can be achieved only with a comprehensive approach using modern high-performance equipment [9,10] and innovative technologies, in particular, through the introduction of high-frequency screens of Derrick Corporation, the pump-hydrocyclone systems of JSC Turbonasos, similar to the systems of Engineering Dobersek, the transfer of the MMC mill to the MPSI (MMC and MPSI, respectively, wet self-milling (without balls) and semi-autogenous grinding mills), and preliminary ore crushing to class of +15 +20 mm, etc. Analysis of possible organizational measures to increase the efficiency of gold ore processing at gold recovery plant CJSC "Vasilievsky Rudnik" has shown that in addition to the material and labor costs used at the mill, it is necessary to include such a concept as "lost production" during equipment downtime. In particular, in the current market situation, a decrease in downtime of mills at the gold recovery plant (sometimes even only by 2-3%) can be economically equal or even exceed the amount of annual costs to replace their lining. In addition, it is necessary to introduce an effective system of automating the main production processes at the gold recovery plant. In particular, its implementation will increase the pump's performance until the replacement of their lining at a minimum to 900-1200 hours (according to practical operational experience).

The need to increase the yield of the gold-containing concentrate of jigging machines has shown the high expediency of introducing the concentrate of the main jigging of concentration tables at the first re-cleaning (with strict observance of the requirements for their coverage). The introduction of all these measures allowed increasing the extraction of gold in the cycle of gravitational concentration by 30%. In the process of thickening, it is necessary to ensure the introduction of automation systems that increase the efficiency of this technology by 15-20%. It is also necessary to use lime with a high activity, which significantly (by 2-3 times) reduces the period of processing time. It is also advisable to change the sampling map available at CJSC "Vasilievsky Rudnik" (Table 2) with the maximum possible application of automatic sampling, and also online output of data in the monitor by operators (for

timely taking the necessary measures). If automatic samplers for testing the sub-black product at the MMC mill (as the most representative point for testing the incoming gold ore) are added to the automatic samplers on the tailings of sorption and on the cyanidation feed, then the compilation and accuracy of gold balance as a whole become significantly easier.

Table 2. Technological sampling map [8]

Name	Selection period	Controlled parameter	Method and type of sampling device
Initial ore	Each batch	The size of minerals, composition; humidity and density	Manual method, breakage of individual pieces with a hammer with a chisel
Coarsed-crushed product	Every 4 hours	Size; Au	Automatic Bucket Sampler
The sublattice screening product	Every 2 hours	Au Concentration	Manual method, bucket sampler
Concentrate and tailings of jigging	Every 2 hours	Au Concentration	Manual method, bucket sampler
Magnetic and non-magnetic fraction	Every 2 hours	Au Concentration	Manual method, bucket sampler
Concentrate, industrial product and tailings of the 1st re-cleaning	Every 2 hours	Au Concentration	Manual method, bucket sampler
Concentrate, industrial product and tailings of the IInd, IIId, IVth re-cleaning	Every 2 hours	Au Concentration	Manual method, bucket sampler
Classification sands	Every 2 hours	Content of 0,074 mm class	Automatic Sampler
Drain of classification	Every 1-2 hours	pH; NaCN concentration, humidity; Au	Manual, bucket sampler
Chips into a disposal area	Every 4 hours	Au	Manual, bucket sampler
Thickened product	Every 2 hours	Au	Manual, bucket sampler
Water in circulation	Every 4 hours	Au	Manual, bucket sampler
Pulp after cyanidation	Every 2 hours	pH; NaCN concentration	Manual, bucket sampler
Saturated solution	Every hour	Au; reagent concentration	Manual, bucket sampler
Sorbent for desorption	Every hour	Au	Manual, bucket sampler
Product of cyanide neutralization	Every 4 hours	NaCN concentration	Manual, bucket sampler
Sorbent into circulation	Every 4 hours	Au	Manual, bucket sampler

Tailings	Every 2 hours	NaCn concentration; Au, humidity	Manual, bucket sampler

Improvement of crusher and mill designs

The existing crushers and mills have a significant disadvantages: these are the crushing and grinding of the uncovered grains of gangue, the content of which is enormous, hence, the costs of these processes can reach significant values depending on the deposits of these minerals. The authors proposed a new device for selective crushing of material (Fig. 3) [10]. It consists of a grinding table 1 made in the form of a fire grate of a predetermined slot size through which the crushed material enters the hopper 4 for perishable material and the rolls 2.

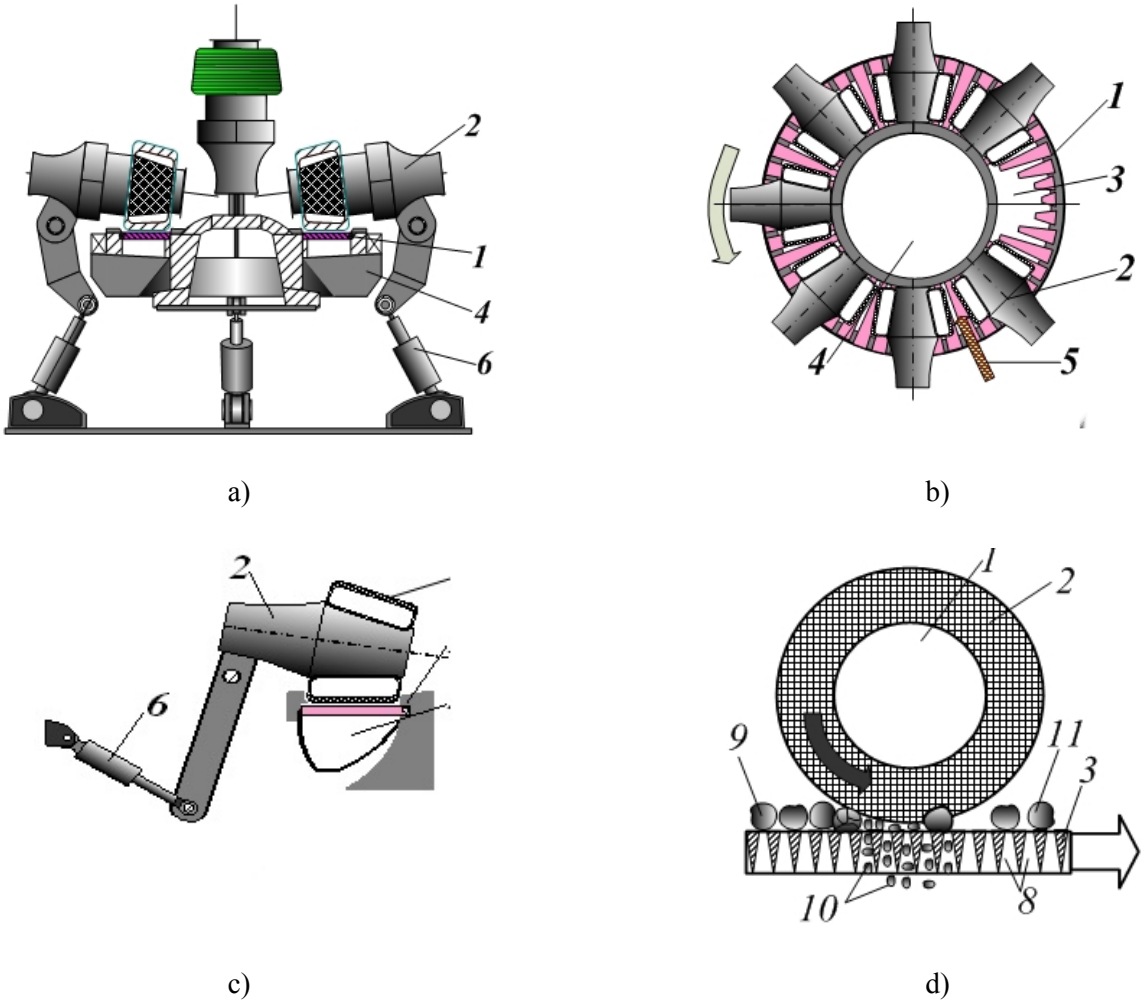


Figure 3. Selective crushing apparatus: a - general view; b - view from the top; c - roll; d - fracture fragment: 1 - roll; 2 - inflatable shell; 3 – fire grates of the grinding table; 4 – hoppers for solid and soft product; 5 - feeding the product to the table; 6 - device for changing the load on the roll; 7 - rubber cover; 8 - gap between the fire grates; 9 - material for crushing; 10, 11 - destroyed and not destroyed material, respectively

The elements of the fire grate in a given place from the horizontal position momentarily go to the vertical one for discharge into the hopper 3 for the crushed pieces of strong material, and the working surface of the rolls is made in the form of an inflatable rubber casing (in the form of an automobile ramp) [8, 9, 11]

Thus, the effect of selective crushing lies in the fact that the pieces of material located on the moving table 1 under the roll are subjected to a mechanical stress, which value exceeds the tensile strength for one material and is less than the strength of the second one. A hard piece of material deforms the inflatable shell, which practically does not change the acting mechanical stress and the overall gap between the roll and the working table of the unit. Due to the action of practically unchanged mechanical stress, a

piece of less fragile material is crushed to the size of the slots between the fire grates of the working table and falling through these slots into the receiving hopper 4. Pieces of hard material remain on the table until they are unloaded into hopper 3 [12].

The crusher for selectively destroying the material includes a horizontally mounted grinding table 1 rotating around a vertical axis through which rolls elements 2 are rolling, the working surface of which is made of an inflatable rubber casing 7, the pressure and the gap between the roll and the table are adjusted by the device 6. The working surface of the table is made of individual fire grates 3, which form slots 8 of a size corresponding to the diameter of a piece of ground material 11, and can rotate for a certain time at a given place of the table around one of their ends, for unloading of large, uncrushed material 11 (the removal of a durable material from the grinding table can be carried out by an additionally installed scraper).

The device works as follows. The material is continuously fed into the input power supply device from where it enters the working table 1 before the first roll is in the place 5. After crushing pieces of a useful rock, the components and dropping through the slots of 8 fire grate, whole pieces of gangue remain on the table (because they deform the inflatable shell of the roll, and, due to Pascal's law, the mechanical stress is slightly increased). All that is left on the table after all the crushing processes is removed from it in any way, for example, it is blown away by air, or by turning a certain number of fire grates around the vertical axis above the ore hopper the gangue 7, or by using an additional scraper. After unloading the coarse fraction, the fire grates rotate in the working state ensuring the continuity of the selective crushing process. To remove the non-magnetic components from the crushed material, in case of magnetite ores crushing, it is proposed to install the magnetic separator developed by us with simultaneously rotating working drum and a magnetic system [13]. Thus, selective crushing is effectively implemented in the concentration of ores of ferrous and non-ferrous metals and in the case when the fracture strength of the mineral component containing the useful component is significantly less than the strength of the mineral constituent of the gangue. When performing grinding, the gangue and rock splices as tailings of concentration are removed into one hopper of a large material, and ore minerals containing a useful component and easily crushed are pulled out as an intermediate product (concentrate). The results of preliminary studies on the concentration of oxidized quartzites (Krivbass, Ukraine) have shown the possibility of obtaining concentrates with a mass fraction of iron up to 60.6% with the extraction of 76.9%. The mass fraction of iron in the tailings is 14.1% [14].

Conclusion

1. One ore body is identified confined to the Magistralnaya quartz vein. The northern part of the "Gerfed" deposit has a distinctive feature - it is characterized by the continuity of ore lenses, without perceptions and apophyses. The thickness of ore intervals varies from 0.5 to 10 m. The distribution of gold in the field is uneven (the content variation coefficient reaches 200). The complexity of the geological structure of the deposit refers to the third group - "medium and large mineralized zones with ore bodies with a thickness of 3-5 m and more."

2. Four blocks were established for the experimental-industrial production. The content and reserves of gold in these areas are small (1-2 g/t). VL-110 of the edge value and VL-35 pass in the middle of the deposit. According to preliminary data, the transfer of this line will cost at least 130 million rubles. The approved reserves for the project do not include part of the deposit under the power line, and these reserves account for 30 to 40% of the total deposit by different estimates.

A new system of head sampling at the gold recovery plant was developed and introduced, which allowed us sharply improve the reliability of the results, reduce labor costs and decrease the number of samples taken by the laboratory from this operation by 6 times.

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