The new paradigm of an environmentally-driven resource-saving technologies for processing of mining

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Abstract. The paper presents the results of theoretical and experimental studies into the development of scientific and methodological bases of environmentally-driven resource-saving technologies for mining waste processing. It is shown that the logic of reconstructing the natural cycles of natural resource equilibrium requires the inclusion of large-tonnage wastes in the status of their technogenic mineral resources in highly efficient, resource-efficient processing, which determines the need to develop innovative technologies for processing wastes very diverse in composition and properties within the framework of the principle of a systematic approach. The methodological basis of theoretical development of new environmentally oriented technologies for waste processing defines the method of scientific knowledge as an ascent from the abstract to the concrete and the construction of technologies according to the developed general algorithm. In accordance with the general methodological approach being developed, technologies have been developed for processing certain types of mining waste - off-balance copper ores from the dump, stale tailings of gold ore from the tailings; iron-zinc-containing blast furnace sludges of metallurgical production by combining several enrichment or concentration and hydrometallurgical methods. The developed resource-saving, environmentally friendly technologies provide the opportunity to involve previously unused resources of technogenic origin into efficient operation with obtaining conditioned metal-containing products and reduce environmental stress in regions with a developed mining and metallurgical industry.

1. Introduction

Given the limited nature of almost all types of natural resources and the significant depletion of the mineral resource base, waste from the extraction and processing of mineral raw materials, stored for a long time, as well as current and replenished, are not only the main environmental pollutants, but also inevitably become a potential raw material base for production ferrous, non-ferrous, noble, rare metals and other by-products [1-4]. This requires the development of fundamentally new technologies that allow for deep selective extraction of valuable components with high qualitative and quantitative indicators [5-7]. The environmental focus of the developed technologies is manifested in their significant difference from the existing methods for processing mineral raw materials [8].
Waste itself is a special type of raw material: it is the subject of labor, since in essence it is an indirect result of perfect labor. The property of wastes to be “secondary” raw materials does not record just the sequence of phases of the previous production, but rather indicates the possibility of a qualitatively different combination of the properties of the substances of the primary processed material. Therefore, while traditional mining technologies are based solely on the exploitation of specific chemical properties of the feedstock while ignoring other properties unused in the technology, the innovative component of environmentally-oriented technologies for waste processing inevitably unfolds them in the integrity aspect of all chemical properties of the available material. Now, the isolation and operation of individual waste properties are based on a comprehensive analysis of the system of all available properties. Thus, the technology of waste processing in achieving effective transformation of their existing properties into the desired final product of a new production cycle in scientific analysis is methodologically characterized as a dialectic unity of the laws of the general and the individual.

The socio-axiological aspect of the problem of mining waste is also important [9]. Wastes generated in the process or upon completion of a certain human activity as “unplanned” products, as a kind of interruption of the natural continuous process of the circulation of substances, are the result of irrational use of resources and at the same time destructively transform the natural environment [10,11]. The logic of reconstructing the natural cycles of natural resource equilibrium requires the inclusion of large-tonnage mining wastes in the status of their technogenic mineral resources in highly efficient, resource-saving, environmentally-friendly processing [12,13].

2. Scientific and methodological foundations of theoretical models of resource-saving technologies for complex and deep processing of mineral waste

The basis for improving and developing existing and creating new technological processes for processing natural and technogenic raw materials is the properties of individual minerals, mineral phases and mineral associations at the macro, micro and nanoscale levels, as well as changes in these properties during the primary technological impact and in secondary hypergenic processes, which and will determine the indicators of their processing [14,15]. If for ores their material composition and technological properties are a function, first of all, of certain conditions for the formation of a deposit and in general have a mineralogical nature, then for mineral raw materials of technogenic origin, the multiplicity of conditions for the formation of both the mineral waste itself and man-made deposits, as local accumulations of these wastes, allows us to talk about a significant difference in the technological properties of technogenic raw materials in comparison with natural and significant differences in material the composition and properties of waste of various origins among themselves [16-18]. These facts determine the need to develop innovative technologies for waste processing within the framework of the principle of a systematic approach. The practical methods of using waste as raw materials in new production cycles should take into account the scientific analysis of the hierarchy of their properties, the structuring of their chemical bonds. The conducted studies convincingly show that the effectiveness of the developed environmentally-friendly technologies directly depends on the degree of revealing the properties of the waste structure.

The material composition and technological properties of mining waste are formed under the influence of a large number of factors in the technological processes of extraction and enrichment of natural mineral raw materials, in metallurgical and chemical processes of processing of enrichment products, in the physical and chemical processes of segregation, gravitational differentiation, weathering, oxidation, natural leaching during storage and waste storage, which determines them as complex mineral systems of technogenic origin and difficult objects for enrichment based on dividing attributes [12]. Therefore, waste should be considered as multi-element structures or multi-factor media that develop according to the principles of open systems, have internal non-linearity, which leads to the presence of more than one stable state. Therefore, the scientific development of resource-saving technologies must necessarily be developed as part of an interdisciplinary synergetic approach. In turn, within the framework of a holistic picture of the world, these technologies confidently occupy
a niche for restoring the integrity of the natural environment and, thereby, restore the integrity of the interaction of the world as a human environment and of the person [19].

The most justified is the formation of processing technologies for refractory technogenic mineral raw materials based on a general scientific and methodological approach to a comprehensive and in-depth study, evaluation of raw materials, an informed choice of technological solutions, techniques, processing methods and their combinations, if necessary, adaptation of known technological solutions to the characteristics of the material composition and specific technological properties of mineral waste [20,21]. In accordance with the general methodological approach, built on the principle of sequentially solving tactical tasks and implementing a set of analytical, experimental, technological work at several subordinate levels, the parameters were substantiated and resource-producing environmentally friendly technologies for the deep processing of certain types of technogenic resources were obtained to produce conditioned, demanded metal-containing products.

3. Objects and research methods
The objects of the study were mining waste in the form of off-balance copper ores located in the dump; gold ore dressing waste - stale dressing tailings stored in an old-year tailing dump; waste from high-temperature metallurgical processes - sludge generated in wet blast furnace gas cleaning systems. All these wastes are characterized by large volumes of their current generation and accumulated reserves, high value and demand as ferrous and non-ferrous precious metals resources, but at the same time they are mineralogically and technologically difficult to process.

To develop mining waste processing technologies, we used complex analytical and mineralogical studies of the material composition and technological properties of the objects of study using modern methods of optical and electron microscopy, X-ray and X-ray spectral analyzes, technological testing using magnetic separation, gravity, flotation, leaching methods, and enlarged laboratory technological studies and semi-industrial tests have developed technology.

4. Results and discussion
Flotation-hydrometallurgical technology was developed for copper ore mining waste — off-balance oxidized copper ores stored in a dump, in which ore mineralization is represented to various degrees by oxidized forms of copper in very complex combinations and relationships with each other and with rock-forming minerals [22]. Ores are difficult to concentrate, since 47% of copper is in the form of secondary sulfide minerals (covellite, chalcosine), 6% is chalcopyrite, 47% is in oxidized minerals (malachite, azurite, chrysocolla).

An innovative solution to the developed technology was non-acid sulfate-ammonium leaching of hard-floating oxidized copper minerals during intensifying mechanical and thermal stresses during ore grinding. For this, the complexing reagent ammonium sulfate was supplied directly to the ore grinding process from a concentration of 133 g / dm³ in the liquid phase, while oxidized copper minerals were dissolved and transferred to a solution in the form of water-soluble complex compounds of copper (II) tetra-aqua ammonia. Flotation of crushed ore resulted in the first copper product - a high-quality copper concentrate with a copper content of 27-29%.

The flotation concentrate and tailings were dehydrated by condensation and filtration, and the liquid phase separated with a copper ion concentration of 0.9-1.2 g / dm³ was a productive leaching solution. During the processing of the productive solution by sorption on Lewatit TP 209 XL cation exchange resin and by electrolysis, a second copper product was obtained - cathode copper with a copper content of 99.99%. Pilot tests of the technology for processing off-balance mixed copper ore from the dump showed its high technological efficiency - the total recovery of copper into copper concentrate and cathode copper exceeded 87% and environmental safety when using non-acid ammonia leaching reagent.

The established laws governing the formation of the technogenic solid of the tailings of the gold recovery factory and the transformation of the technological properties of gold and mineral associations in it determined the choice of different methods for extracting gold from different parts of
the tailings. In the old-year-old mothballed tailing dump of one of the gold-mining plants in the Republic of Bashkortostan, 2.6 million tons of stale tailings of gold ore processing with gold reserves of 3.2 tons with an average grade of 1.23 g / t were stored. During hydraulic storage and storage of tailings, several characteristic geological and mineralogical zones were formed with various morphometric parameters of technogenic gold and lithological and filtration properties of the technogenic deposit [23].

Gravitational recovery of relatively large and small gold is most expedient to be carried out from the drained, small power sections of the beach zone of the tailing dump at centrifugal concentrators. A gravitational enrichment scheme has been developed, which includes two-stage grinding of sands extracted from the beach zone of the tailing dump, the main, control and cleanup separations on modified centrifugal separators, and dehydration of the resulting gravitational concentrate. Pilot industrial tests of the technology have confirmed the effectiveness of the adaptation of the design parameters of centrifugal separators to the morphometric parameters of fine and fine gold from sections of the beach zone of the tailings. When processing sands with a gold content of 1.5 g / t, a fairly high recovery of gold in concentrate of 65% was achieved with a gold content of 45.6 g / t [24].

To extract fine and fine gold from the central mainly flooded part of the tailings pond, a geotechnological scheme for processing stale tails at the place of their storage in the tailings pond was developed. The main importance was to increase the environmental safety of the technology compared to cyanidation; therefore, the use of chlorine-containing leaching solutions was justified as non-cyanide, environmentally safer gold solvents. During leaching with working solutions of chlorine water with a concentration of active chlorine of 100-5000 mg / dm³ at pH = 2.0÷2.9 were pumped to the surface productive solutions with a concentration of active chlorine of 0.10-0.12 g / dm³ and gold were 0.2÷0.85 mg / dm³ at a pH in the range of 4.0 ÷ 2.4, the processing of which in sorption pressure columns with a clamped layer of sorbent - activated carbon grade AG-3 - provided saturated carbon with a gold content of up to 5 kg / t for further metallurgical processing to obtain a Dore alloy [24].

The technological process of downhole leaching of gold at the place of occurrence with sorption processing of productive solutions is characterized by: the lowest capital and operating costs; quick commissioning and receipt of marketable products; closed loop circulation of solutions, without the formation of secondary waste; environmentally friendly technology without breaking the continuity of the technogenic array, with a practically untouched surface of the landfill. The combination of gravitational additional extraction of gold from the beach area and borehole chloride leaching of gold at the location of the tailings in the central part of the technogenic solid will ensure the most complete development of the reserves of this technogenic gold-bearing object.

A comprehensive study of the characteristics of the mineral composition, technological properties of iron-zinc-containing fine waste generated in high-temperature blast furnace processes, and technological testing of the behavior of iron-and-zinc-containing components of sludges in traditional magnetic, gravity, flotation concentration processes, made it possible to adapt them to the properties of secondary metal-containing raw materials of ferrous metallurgy. A combined flotation-magnetic technology for complex processing of blast furnace slurry was developed, including reverse flotation using amine-based cationic collectors for predominant concentration of zinc-containing minerals in the foam flotation product, and wet magnetic separation of the flotation chamber product for selective concentration of iron-containing minerals [25].

When processing blast furnace sludges from the Magnitogorsk metallurgical plant with an iron content of 48%, zinc - 1.37%, zinc-containing by-product with zinc content of 7.1%, iron - 18.31%, and iron concentrate with an iron content of 60.5% obtained by this scheme zinc - 0.4% are recyclable products, respectively, at non-ferrous metallurgy enterprises and in the charge of sinter production. Innovative, environmentally friendly, low-cost combined technology for the integrated processing of blast furnace sludge to produce additional products that are in demand in related industries of ferrous and non-ferrous metallurgy provides an increase in the recoverable value of secondary resources of ferrous metallurgy and their most complete recovery as part of industrial recycling.
5. Conclusions
Thus, the methodological basis for the theoretical development of environmentally-friendly technologies for waste processing should determine such a theoretical method of scientific knowledge as the method of ascent from abstract to concrete. Methodologically new resource-saving technologies for processing various types of mineral waste have the property of universality, as they have an organized general construction algorithm. The initial hypothetical or experimental identification of some main relationship or relationship of waste properties involves a subsequent analysis of its modifications under various conditions. This becomes the basis for the discovery of new relationships of waste properties, which allows us to establish their interactions and, thus, leads to the generation of a specific method (technology) for obtaining the desired product in the process of involving waste in a new production cycle.

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