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Technological support for the processing of technogenic mineral formations

Boris Valer'evich FRANTSUZOV[1]
Andrey Nikolaevich IVANOV[2*]
Vladimir Evgen'evich STROVSKIY[2**]
Vera Vasil'evna YURAK[2,3,4***]

[1]Ministry of Natural Resources and the Environment of the Russian Federation, Moscow, Russia
[2]Ural State Mining University, Ekaterinburg, Russia
[3]Institute of Economics of the Ural Branch of the Russian Academy of Sciences, Ekaterinburg, Russia
[4]Empress Catherine II Saint Petersburg Mining University, Saint Petersburg, Russia

Abstract

Relevance. In the current conditions of depletion of the mineral resource base (MRB) and deterioration of the quality characteristics of newly discovered mineral deposits, the problem of using technogenic mineral formations is of particular relevance, which requires identifying a range of problems that impede the introduction of technogenic deposits into economic circulation, and also requires the development of proposals for the development of activities for the processing of technogenic mineral formations in the conditions of the Russian Federation.

The purpose of the study is to analyze the current state of technological support for the development of technogenic deposits and assess the prospects for developing a technology for processing technogenic mineral formations.

Research methods are a systems approach, methods of structural-logical, economic and statistical analysis.

Research results. The importance of technological support in the implementation of projects for the development of technogenic deposits is substantiated. The innovative nature of technologies for processing technogenic mineral formations (TMF) is proven, taking into account the specifics of technogenic deposits that distinguish them from natural deposits. Examples of the use of new technologies, the results of laboratory studies, and the fundamental principles of developing new technologies are given. Particular attention is paid to the principle of environmental safety. The need to involve eco-business in the development of innovative technologies, as well as to provide state support, is substantiated.

Conclusions. The development of innovative technologies for processing TMF requires the development of small environmental entrepreneurship and the provision of state support for this activity. It is necessary to improve the regulatory framework of the Russian Federation in terms of providing 1) the possibility of financing research and development work of small enterprises developing and improving TMF processing technologies, as well as 2) the possibility of organizing public-private partnerships for the development of TMF placement sites.

***Keywords*:** technogenic deposits, technologies, principles, eco-business, development, state support.

Introduction

Currently, about 100 billion tons of solid waste are located on the territory of Russia, more than 90% of which are waste from mining and related processing industries (technogenic mineral formations – TMF). The host rocks located in dumps, as well as the waste material of beneficiation filling tailings and sludge storage facilities, serve as a source of extracting useful components from them. Objects from which the extraction of useful components is profitable fall in the category of technogenic deposits. The depletion of modern natural mineral raw material base, the deterioration of the natural characteristics of newly discovered deposits predetermines the use of technogenic deposits to maintain the sustainability of natural mineral raw material base. The priority of one problem is generally recognized, but its implementation is hampered by a number of problems, one of which is the lack of new technologies that are different from traditional ones, ensuring the maximization of the extraction of useful components while maintaining environmental safety, conditions conducive to the preservation of the biotic potential of the territory.

✉GrayKardinal@yandex.ru
**ief.etp@m.ursmu.ru
***vera_yurak@mail.ru

At the beginning of the 21st century, In the Ecological Doctrine of the Russian Federation, approved by Government Order No. 1225r dated 31.10.2002, the "low technological and organizational level of the economy" was noted among the factors of degradation of the natural environment of the Russian Federation, and paradoxically, this problem remains unresolved to this day [1]. Technology is considered as the implementation of the results of science in material production. According to [2], "Technology (from the Greek techno – the art of craftsmanship, skill and logos – word, teaching) is a set of methods for processing, manufacturing, changing the state of properties, shape, raw materials, materials or semi-finished products used in production processes to obtain finished products; the science of the methods of influencing raw materials, materials and semi-finished products with the appropriate production tools. "The importance of technology for activating the process of developing technogenic deposits (TD) is also evidenced by the fact that a license is issued to a subsoil user only if there is technology for processing technogenic mineral formations (TMF). Moreover, "availability of technology" is even recommended to be used as a classification feature, highlighting:

– TMF with processing technology;

– TMF whose technologies are at the test output stage;

– TMF whose technologies are undergoing laboratory testing;

– TMF that do not have processing technology.

The peculiarity of technologies in terms of using technogenic deposits is, first of all, their unconventionality, caused by the novelty and uncertainty of the properties of technogenic mineral formations, which makes it impossible to use standard equipment and standard schemes. The inefficiency of using traditional technologies in processing technogenic raw materials is explained not only by the low level of extraction of useful components, which causes the unprofitability of the development of TMF, but also by the high probability of environmental problems [2]. Newly created technologies must be resource-saving and environmentally safe, i. e. meet the level of BAT for the intensity of impact on the environment.

The difference between technogenic deposits and natural ones is primarily determined by the process of their formation itself, which, by definition [3], is called lithotechnogenesis (belonging to exogenous geological processes occurring in the uppermost part of the lithosphere) [4, 5]. Like natural lithogenesis (formation of sedimentary rocks), lithotechnogenesis occurs in several stages, often in very unusual conditions caused by industrial activities. Its first stage is associated with the extraction of rock from the subsoil, its separation from the massif, crushing and transportation to storage sites (hard and loose rocks or poor, substandard ores). During beneficiation, this is the accumulation of tailings, and during metallurgical processing, sludge. The second stage is associated with the formation of the "bed or layer" itself, i. e. the formation of a geological body of a potential technogenic deposit. The end of this stage is considered to be the formation of a dump or filling of a sludge storage facility. The third stage will be reflected in the change in the physical-mechanical and physical-chemical properties of technogenic mineral formations in surface conditions. This may be the weathering of less stable rocks located in waste heaps, the combustion of coal waste heaps, the oxidation of sulphides in waste heaps of pyrite deposits, in sludge storage facilities of non-ferrous metallurgy processing plants, etc.

In general, the following features are characteristic of technogenic mineral formations:

– polycomponent composition (combination of natural and technogenic components);

– dependence on the geochemical characteristics of the mineral raw materials on the basis of which the TMF is formed;

– dependence on the technology, ore preparation and beneficiation (chemical reagents used) [6];

– variable granular composition;

– often high dispersion;

– presence of amorphous formations;

– fairly low content of useful components;

– polymineral aggregates;

– secondary changes associated mainly with the process of hyper-genesis [7].

Researchers also note the presence of a wide variety of valuable components and the absence of any patterns in their distribution within the TMF [8]. The materials of TMF tailings and sludge storage facilities differ from natural deposits not only in granular composition, but also in the content of a number of chemical substances and new formations that arise during processing and storage. The initial qualities of the material of these TMF change significantly under the influence of a number of factors:

– joint storage of rocks with different compositions and physical and mechanical properties;

– gravitational differentiation and segregation of storage of solid mineral deposits;

– mixing, oxidation, leaching, migration and redistribution of components [9].

The material of tailings storage facilities is usually fine-grained or finely dispersed, with varying degrees of water-logging: (tailings storage facilities can be dry, wet, waterlogged, with internal quicksand zones). As a result of gravitational differentiation processes over time, fairly large metal-enriched technogenic deposits are formed in the tailings, and deposits similar to secondary beneficiation zones can be formed in the lower part of the tailings storage facilities [10]. Thus, all of the above confirms the specificity of the formation of technogenic deposits. Their complex chemical, mineralogical and granular composition, a wide range of valuable and harmful components, and the multi-variant nature of use require an individual approach when assessing its individual components and developing solutions regarding technologies.

The possibility of developing a technogenic deposit, as noted earlier, depends on the degree of efficiency of technologies, their use of geotechnological methods. According to the Russian Metallogenic Dictionary, the latter include "chemical, physicochemical, biochemical and microbiological methods of extracting minerals" [11]. Modern geotechnological methods are represented by: borehole, heap (vat) and block leaching, borehole hydraulic mining, underground dissolution of salts, underground gasification. Hydrometallurgical methods of processing have significant efficiency in processing TMF, opening up wide opportunities for extracting metals from TMF, which in some cases are not available to traditional processing methods.

It cannot be assumed that new technologies for processing TMF do not exist at all. Examples of their creation and use exist, but they are very few in number. In addition to examples of implemented technologies, there are a large number of scientific developments confirming the possibility of using TMF [12]. Most often, the results of laboratory studies are reflected, characterizing the methods of obtaining copper, gold, rare earth metals, molybdenum, quartz concentrate, etc. However, further progress in research is not reflected in literary sources, which most often indicates that at best the pilot stage has been reached and there are no facts of implementation in production [13–15]. Very low patent activity is noted in the field of technologies for processing technogenic raw materials. Existing patents are not supported, which indicates a lack of demand for them [16]. Taking into account all the requirements for TMF processing technologies, they can rightfully be defined as innovative, which in the most general sense are characterized as "changes leading to the same volumes of production (goods and services), but with lower costs (material and financial)" or as innovative technologies.

Priority areas for the development of exploratory and applied scientific research in the field of industrial-scale use of waste from the extraction and processing of minerals are reflected in table 1 [17].

Among the fundamental principles recommended for the development of technologies are the following:

– the principle of double effect – supplementing the economic effect obtained by extracting useful components from waste with an environmental effect;

– the principle of balance of interests – coordination of the interests of waste users, their owners, and the population living in the waste disposal area;

– the principle of legality – compliance with restrictions stipulated by regulatory and legal acts;

– the principle of humanization – preventing deterioration of the quality of the environment and living conditions of the population;

– the principle of innovation – use of modern geotechnological methods in the technologies being developed;

– the principle of import substitution – exclusion of imported materials, parts, units in technical equipment involved in the technological process, and imported reagents;

– the principle of waste capacity – minimization or exclusion of waste generation;

– the principle of environmental friendliness – minimization of the negative impact on the environment;

– the principle of economy – affordability for users.

The initial premise of creating technologies for processing TMF is resource conservation (maximum extraction of valuable components from waste), but ensuring environmental safety is no less important. The principles of constructing environmentally friendly geotechnologies are reflected in the works [18, 19]. The main condition for solving this problem is "creating equal opportunities for the development of the technosphere and biosphere" [18], i. e. developing such an eco-technology that is built according to the type of processes characteristic of nature. In general, at present, as the authors believe [20], various methods of physical and chemical technologies (PCT) "are at the threshold of initial large-scale industrial development", but with appropriate government support for funding research and experimental industrial development, as well as economic incentives for entities investing in the creation and operation of enterprises based on PCT, it is possible to expand the scale of industrial application of these technologies in a fairly short time.

As follows from generally accepted practice, fundamental research (free and targeted) is today mainly the subject of

Таблица 1. Приоритетные направления поисковых и прикладных научных исследований в области использования в промышленных масштабах отходов добычи и переработки полезных ископаемых
Table 1. Priority areas of exploratory and applied scientific research in the field of industrial-scale use of waste from the extraction and processing of minerals

Directions	Tasks
I. Substantiation and development of technological processes for the extraction of valuable useful components from waste from the extraction and processing of minerals	1. Adaptation of mineral beneficiation processes and machinery to technogenic raw materials 2. Study of chemical and phase composition, structure and technological properties of waste from mining and processing of minerals 3. Development of highly efficient, energy-saving methods and equipment for inter-granular destruction of rocks 4. Extraction of inert (chemically stable) components from waste from mining and beneficiation of ores 5. Leaching of waste from mining and beneficiation of ores at the place of their occurrence or storage 6. Modification of technological properties of useful components in waste from mining and processing (energy impacts, electrical processing, mechanical activation, etc.)
II. Combination of physical and chemical beneficiation methods (flotation, etc.) with chemical and metallurgical methods (pyro- and hydrometallurgy, autoclave leaching, electrochemical and biological oxidation)	1. New methods and techniques for extracting valuable components from difficult-to-enrich technogenic raw materials 2. Rational methods for obtaining bulk concentrates and their processing by pyrometallurgical and hydrometallurgical methods
III. Substantiation and development of technological processes for obtaining additional finished products from the non-metallic part of mining and processing waste for secondary use	1. Development of technologies and conditions for the utilization of waste from the extraction of non-metallic mineral ores and coals in the construction industry 2. Utilization of beneficiation tailings as part of backfill mixtures during the extraction of minerals 3. Processing and use of technogenic hydromineral raw materials

academic science, science of higher educational institutions, and specialized scientific centers. The implementation of conceptual solutions in applied research is carried out in almost all scientific institutions and is accompanied by a particularly high risk. Applied research, experimental design and development were previously carried out mainly in industry specialized institutes, while the developed technical solutions were transferred for development in production. The destruction of industry science today presupposes the formation of small innovative eco-firms (development of small businesses) which, possessing positive results of applied research and design and technological developments, aim to transform technical solutions into production and their subsequent practical implementation.

The success of small enterprises with an innovative profile is explained by a number of reasons:

– firstly, in-depth specialization ensures high competitiveness of small enterprises in the development of technological solutions compared to large organizations even with rather limited financial resources;

– secondly, narrow subject specialization makes it possible to combine production activities with the experimental production process;

– thirdly, all stages of the innovation process in small enterprises are combined under the leadership of one person, which accelerates the achievement of the final result;

– fourthly, a wide range of studies that specialists of small enterprises have to do due to the small number of teams contributes to the development of new ideas and new approaches to solving the set goal.

World experience in the development of innovative activities has proven that the activities of small firms are most intensive during the period of creation and development of a new industry, which is directly related to the formation of a new industry of material production for the development of man-made raw materials potential. Another feature of eco-business is the regulatory role of the state, since the market itself is not fully oriented towards the implementation of environmental innovations. The task of the state is to create favorable conditions for the priority development of eco-business, including the provision of the necessary state support.

The behavior patterns of innovative eco-firms are determined by the availability of start-up capital. At the first stage, teams of small enterprises in the higher education system and other state-owned institutions are attracted to perform fundamental research. The results of the activity are ideas, models, and prototypes. The number of employees in such small enterprises is usually insignificant; the majority of employees are attracted under a contract. Such research is financed by the state as state assignments, and less often by large companies as contractual research. When concluding contracts, the innovativeness of research centers (state or privately owned) is ranked. In some cases, the teams of these firms also perform applied research (design and technological developments).

Possessing technical solutions in relation to technologies, innovative eco-firms of private ownership combine their property with other entrepreneurs to implement collective entrepreneurial actions to develop technogenic deposits. Their contributions to the authorized capital are intellectual products in the form of new or improved versions of basic technologies, as well as a set of skills and production experience necessary for organizing production on their basis (know-how), one of the main features of which is the element of confidentiality. This model of behavior is distinguished by a situation of either insignificant start-up capital or large scales of developed technogenic deposits requiring significant capital investments.

Another model in the development of innovative eco-business is also possible, which provides for the expansion of cooperation with it by large businesses, which is associated with the formation of a kind of symbiosis of large and small businesses with new forms of organizing mutual participation between them. Due to the fact that one of the main channels of communication between them is financial, its implementation is supposed to be through the expansion of the network of venture firms: investments in independent venture firms, the organization of their own subsidiary venture firms with the involvement of talented people and the creation of small innovative firms using loans. An example of the effective creation of a small enterprise to ensure the production activities of a large company can be the positive experience of ZF PAO MMC Norilsk Nickel in attracting small businesses represented by ZAO Mineralintex to solve the enterprise's problems, including the development of frozen beneficiation waste, a mothballed tailings storage facility. One can expect a strengthening of the connection between science and production within large companies related to the mining and metallurgical complex, the creation of decentralized design bureaus and laboratories in each division, including those related to the development of secondary raw material potential, as well as the establishment of closer cooperation between industrial firms and university and academic science. We are talking about the separation of commercial activities in higher education institutions and academic institutes and the creation of corresponding centers with a significant share of targeted funding from industry. It should be noted that the orientation of the activities of such centers provides for the development of conceptual solutions and their implementation in technical ones.

Small enterprises based on the developed technologies can organize the production process and sell their products both on the domestic and (or) foreign market. Insufficient turnover of products usually forces them to "earn extra money" on commerce, use the premises and equipment of the "parent structure". Enterprises of this group in the field of waste processing make up the majority. Specific for these small enterprises is the use of loans for the purchase of technological equipment and tooling, the solution of environmental issues, expansion of production, licensing and certification of products.

The central place in eco-business belongs to innovators who form the human capital of eco-companies. Human abilities, knowledge and skills are recognized as a special form of capital, as they are an integral personal property of each individual. In the structure of human capital, two components (bases) can be distinguished, based on the possibility of increasing the qualitative level of human capital: the biological base and the information base. Each of them has a starting part and an acquired one. The biological base characterizes the natural properties of a person: health, intuition, appearance, etc. Acquired properties are expressed in their improvement. The information base concerns acquired knowledge, skills, abilities, new competencies. For the conditions of eco-companies engaged in the development and improvement of technologies, both components of human capital are important. Innovators must have a creative beginning, the ability to form new ideas, analytical skills, and a willingness to take responsibility. There is an acute problem of expanding the information base of human capital through the acquisition of fundamental and applied knowledge that is necessary for a given area of activity, a given profession, and qualifications for performing certain functions.

The human capital of eco-firms should be considered in conjunction with the conditions in which it is implemented, because in the presence of unfavorable conditions there is no full return on human capital, the discovery of the abilities of workers does not occur. The creation of conditions concerns the acquisition of the required equipment and hardware, necessary materials, the possibility of attracting part-time workers on preferential terms in terms of taxation. As world experience shows, innovations created in small enterprises are less expensive than in large enterprises, and the number of innovations per employee is several times greater. World experience shows the need for state support for this process, which is important for the national economy. From this point of view, it is necessary to support the recommendations [21] regarding the use of state development institutions – organizations that accumulate resources to support innovative projects using public-private partnership mechanisms. Technologies for prospecting, exploration, development of mineral deposits and their extraction (including technogenic deposits) are among the critical technologies, but development institutions specializing in them have not been created in the territory of the Russian Federation.

Conclusions

Improvement and development of innovative technologies for processing of TMF fully fits into the framework of the concept of their support of small and medium-sized businesses by state development institutions, which requires legislative changes:

– provide in the Federal Law "On Supporting Small and Medium-Sized Entrepreneurship" the possibility of financing research and development work of small and medium-sized businesses developing and improving technologies for the processing of TMF, since at present, according to Article 14, financial support should not be provided to small and medium businesses engaged in the extraction and sale of minerals from natural deposits;

– introduce amendments to the Federal Law "On Public-Private Partnership, Municipal-Private Partnership in the Russian Federation and Amendments to Certain Legislative Acts of the Russian Federation" concerning the objects of public-private partnership agreements. TMF placement facilities should be included in them on full terms.

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Технологическое обеспечение процесса переработки техногенно-минеральных образований

Борис Валерьевич ФРАНЦУЗОВ[1]
Андрей Николаевич ИВАНОВ[2*]
Владимир Евгеньевич СТРОВСКИЙ[2**]
Вера Васильевна ЮРАК[2,3,4***]

[1]Министерство природных ресурсов и экологии Российской Федерации, Москва, Россия
[2]Уральский государственный горный университет, Екатеринбург, Россия
[3]Институт экономики УрО РАН, Екатеринбург, Россия
[4]Санкт-Петербургский горный университет Императрицы Екатерины II, Санкт-Петербург, Россия

Аннотация

Актуальность. В современных условиях истощения минерально-сырьевой базы (МСБ) и ухудшения качественных характеристик вновь открываемых месторождений полезных ископаемых особую актуальность приобретает проблема использования техногенных минеральных образований, что требует выявления спектра проблем, препятствующих введению техногенных месторождений в хозяйственный оборот, а также требует разработки предложений для развития деятельности по переработке техногенных минеральных образований в условиях Российской Федерации.

Цель исследования – анализ существующего состояния с технологическим обеспечением процесса освоения техногенных месторождений и оценка перспектив разработки технологии переработки техногенных минеральных образований.

Методы исследования – системный подход, методы структурно-логического, экономического и статистического анализа.

Результаты исследования. Обоснована важность технологического обеспечения в реализации проектов по освоению техногенных месторождений. Доказан инновационный характер технологий переработки техногенных минеральных образований (ТМО) с учетом специфики техногенных месторождений, отличающих их от природных месторождений. Приведены примеры использования новых технологий, результаты лабораторных исследований, а также основополагающие принципы разработки новых технологий. Особое внимание уделено принципу экологической безопасности. Обоснована необходимость привлечения экобизнеса к разработке инновационных технологий, а также обеспечения государственной поддержки.

Выводы. Разработка инновационных технологий переработки ТМО требует развития малого экологического предпринимательства и оказания государственной поддержки этой деятельности. Необходимо совершенствование нормативно-правовой базы Российской Федерации в части предоставления 1) возможности финансирования научно-исследовательских и опытно-конструкторских работ малых предприятий, разрабатывающих и совершенствующих технологии переработки ТМО, а также 2) возможности организации государственно-частного партнерства для отработки объектов размещения ТМО.

Ключевые слова: техногенные месторождения, технологии, принципы, экобизнес, развитие, государственная поддержка.

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✉GrayKardinal@yandex.ru
**ief.etp@m.ursmu.ru
***vera_yurak@mail.ru

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