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КОМБИНИРОВАНИЕ ТЕХНОЛОГИЙ ДОБЫЧИ МЕТАЛЛОВ НА ОСНОВЕ БЕЗОТХОДНОГО ВЫЩЕЛАЧИВАНИЯ

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Аннотация: Рассмотрена проблема поддержания минерально-сырьевой базы и минимизации негативного воздействия технологий на окружающую природную среду. Сверхзадачей исследования является комбинирование технологий разработки месторождений так, чтобы при выполнении технологических процессов предыдущего этапа перманентно создавались условия для реализации следующего этапа. Показано, что основным элементом решения проблемы является освоение технологий безотходного извлечения полезных компонентов из хвостов переработки. Методы исследования включает в себя анализ аспектов горного производства и прогнозирование направлений развития технологий добычи и обогащения твердых полезных ископаемых на основе их комбинирования. Детализирована концепция совершенствования процессов добычи и переработки в условиях стохастического развития влияющих факторов. Приведены сведения об извлечении до 80% ранее теряемых металлов при переработке хвостов обогащения полиметаллов Садона, угля Донбасса и железистых кварцитов КМА. Дана типизация методов совершенствования процессов выщелачивания в дезинтеграторе. Сформулирована проблема упрочнения базы добывающих отраслей промышленности. Приведена модель для определения прибыли от комбинирования традиционных и инновационных технологий. Приведены результаты прогнозной оценки возможностей вариантов выщелачивания. В качестве ведущего обозначилась концепция развития ресурсной базы металлургии за счет комбинирования технологий добычи и обогащения руд по критерию извлечения металлов из недр.

Ключевые слова: георесурсы, металлы, добыча, обогащение, выщелачивание, дезинтегратор, извлечение.

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Combining metal extraction technologies based on waste-free leaching

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Abstract: The article discussing the problem connected with sustaining mineral resources and minimizing the negative impact of technology on the environment. The primary objective of the research is to combine field development technologies so that the current phase operations create conditions for the implementation of the next phase. It is shown that the main element of solving the problem is the development of technologies for waste-free extraction of useful components from processing tailings. Research methods include analysis of aspects of mining production and forecasting directions for the development of technologies for the extraction and processing of solid minerals based on their combination. The concept of improving mining and processing processes in conditions of stochastic development of influencing factors is detailed. Information is provided on the recovery of up to 80% of previously lost metals during processing of tailings from the enrichment of polymetals from Sadon, Donbass coal and ferruginous quartzites of the KMA. A typification of methods for improving leaching processes in a disintegrator is given. The problem of strengthening the extractive industries is formulated. A model is presented for determining profits from combining traditional and innovative technologies. The results of a predictive assessment of the possibilities of leaching options are presented. The leading concept was the development of the resource base of metallurgy by combining extraction and processing technologies based on the metal extraction ratio.

Key words: georesources, metals, mining, enrichment, leaching, disintegrator.

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Introduction

The priority of mining production in Russia took shape in the 17th century due to the use of a water wheel, mills with a hydraulic wheel and washing and other innovations of that time.

Nowadays, the problems of depletion of mineral resources and the negative impact of technology on the environment have become more acute [1–3]. Issues of disposal of mining and processing waste form the main problem on a global scale [4–6].

In this context, the main objective is the development of waste-free technologies for the extraction of useful components from processing tailings, and the rehabilitation of lands previously withdrawn from economic use.

Major disadvantages of exploitation of mineral deposit is nonuniform extraction of reserves [7, 8] and incomplete recovery of components from extracted raw materials. The practice of extracting only a part of elements is harmful because the cost of valuable components not extracted from tailing during processing is comparable to the cost of extracted valuable components [9, 10].

In the 16th–17th centuries, mining technology received lifting and drilling machines, a fan, drainage devices, etc. The period of the 1950–70s is characterized by the development of field geophysics, physical chemistry, physical and technical monitoring and technology for the enrichment of low-grade ores of non-ferrous, rare and precious metals, diamonds [11].

A significant part of the book value of fixed assets of the Russian economy is concentrated in the field of extraction and circulation of georesources [12, 13], which explains the relevance of the problem under consideration. Extractive industries provide more than 25% of GDP and about 50% of the country's exports.

Methodology

Studying the historical context and future trends provides an insight into strategies for optimizing mining and processing procedures in the face of unpredictable developments in external and internal factors [14, 15]. This methodology involves a comprehensive analysis of mining operations, including an assessment of the current state of technology, its effectiveness and environmental impact. Forecasting future developments includes not only technical aspects, but also economic, environmental and social factors that may affect the industry [16–18].

Combining different mining and processing technologies is a complex process that requires a deep understanding of both individual methods and their interactions. This includes analyzing the possibilities for integrating new technologies into existing production chains, as well as assessing the potential benefits and risks of such a synthesis. The development of a concept for improving production and processing processes is based on a detailed study of historical data and forecasting changes in influencing factors. This includes the analysis of stochastic models that can help predict likely development scenarios and determine optimal strategies for adapting to changing conditions.

Overall, the proposed research methodology is a multi-level approach that takes into account a wide range of variables and provides comprehensive guidance for making informed decisions in the mining industry. This allows not only improving current processes, but also contributes to the development of new, more efficient and environmentally friendly methods of mineral mining and processing.

The capabilities of technologies with leaching, as a subject of combination, are assessed by the amount of extraction of useful ingredients.

Discussion

The study of the current situation in the Russian mineral resources industry has revealed a number of problematic aspects. One of the key challenges is the lack of attention to recycling and reuse of secondary resources. This is due to the fact that it is more profitable for mining companies to focus their efforts on expanding their main production, which provides an immediate increase in profits. This strategy, although it seems economically justified in the short term, ignores long-term consequences, such as the depletion of natural resources and environmental degradation.

The sustainable recycling of secondary resources requires an integrated approach, including not only technological innovations, but also changes in legislation, economic incentives for enterprises, as well as increased awareness and responsibility at all levels of management. This will create conditions under which the processing of secondary resources will become not only environmentally, but also economically attractive. An important aspect is the development and implementation of advanced technologies that can make the recycling process more efficient and less costly. For example, the use of new sorting and cleaning methods can significantly improve the quality of the resultant secondary raw materials, making them competitive with primary resources [19–21].

In addition, it is necessary to intensify scientific research in the field of waste disposal, which will not only improve the existing methods, but also open up new ways for the use of recycled materials. This may include the development of new materials that can replace traditional ones, or the creation of new products with high added value. In general, to improve the situation in the mineral resources sector of

Table 1

Methods for improving leaching processes in disintegrator

Методы улучшения процессов выщелачивания в дезинтеграторе

Stimulation method	Result	Implementation
Vibration	Increased response surface	Shacking of disintegrator working body
Chemical treatment	Activation of metal extraction to solution	Preventive treatment with reagents

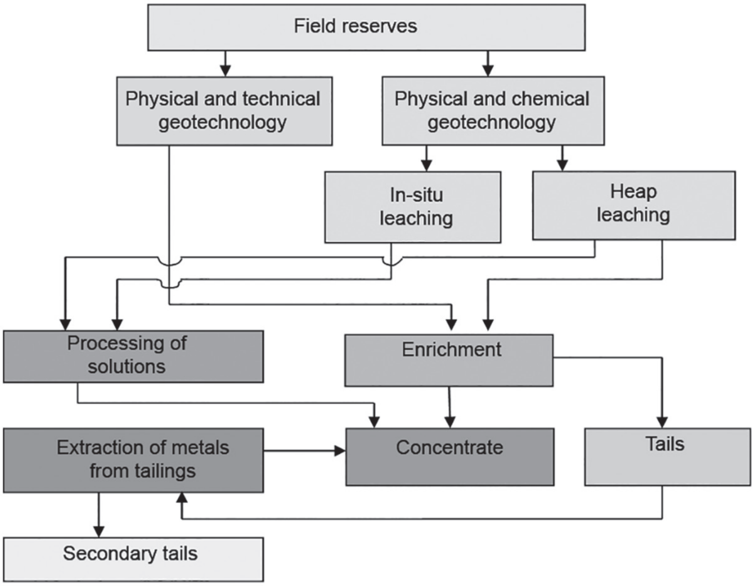
Russia, it is necessary to take a series of measures aimed at stimulating utilization of secondary resources. This will require joint efforts of government, business and society, as well as willingness to change and innovation at all levels of the production economy.

About 80% of ores at depths greater than 1500 m are mined underground. When developing potash and iron ore deposits, the loss of minerals in the subsoil reaches 60% [22]. Integrated mining combines traditional ore extraction for factory processing and in-situ leaching [23].

Directions for improving the combined technology of metal leaching in a disintegrator are systematized in Table 1.

The process of beneficiation of metals from substandard raw materials obtained as a result of mining operations is a key stage in strengthening the mineral resource base for the metallurgical industry. This allows not only to maximize the recovery of valuable metals, but also contributes to a more complete use of extracted resources, which in turn increases the efficiency of the production process. Disintegrator leaching is an innovative method that converts mining waste, such as tailings, into valuable metal products. This process not only helps reduce waste volumes, but also provides an additional source of raw materials for metallurgy, thereby reducing the environmental burden. Disintegrators use mechanical action to break down solid particles, which increases the surface area for chemical interaction during the leaching process. This speeds up chemical reactions and increases the recovery of metals from the tailings. Thus, the use of disintegrators in the leaching process opens up new horizons in waste management and resource conservation. The increased use of leach disintegrators could revolutionize the metallurgical industry by not only recycling waste but also returning it to the production cycle as a useful raw material. This, in turn, can significantly reduce dependence on primary sources of metals and contribute to a more sustainable and environmentally friendly production system.

In the process of extracting metals from oxidized ores, various leaching methods are widely used, including sulfuric acid, chloride and ammonium leaching. These methods can effectively extract valuable components from ore using a variety of equipment such as autoclaves, which are closed reactors that can withstand high pressure and temperature, vats for processing large volumes of ore, and heap and in-situ leaching, which allows treatment of ore immediately at the site of its mining. One of the most innovative and promising methods is heap bioleaching, which uses microorganisms to extract metals from ore. This method is particularly effective at low temperatures, making it ideal for the use in the Far North where traditional methods may be ineffective due to freezing of reagents and materials. Bioleaching is an environmentally friendly alternative to traditional methods as it reduces the consumption of chemicals and energy. In addition, this method makes it possible to extract metals from ores with low contents of va-



Scheme for combining geotechnologies for field development
Схема комбинирования геотехнологий разработки месторождения

luable components, which was previously considered economically unfeasible. Heap bioleaching at sub-zero temperatures is becoming one of the key directions in the development of modern ore processing technologies.

Improvement of metal mining occurs through minimizing costs for unproductive operations.

A whole range of works to combine various technologies includes both extraction of valuable ores with subsequent processing at a production plant, and leaching of metals in specialized blocks, heaps and even disintegrators. This entire process involves a thorough study and application of modern technologies for the extraction and processing of minerals, which requires specialists to have deep knowledge and experience in this field. It is important to note that within the framework of this set of works, the product quality control, constant updating of equipment and the search for new methods for improving the production process are also carried out. In short, activities related to the combination of various technologies are an important and multifaceted area in which each stage plays its role in the overall picture of creating high-quality and competitive products (Figure).

The analysis of accumulated waste from ore processing at non-ferrous metallurgy plants makes it possible to estimate the

Table 2

Potential feedstock for combined processing technologies
Потенциальное сырье для комбинированных технологий переработки

Not extracted, %	Metals							
	Tin	Tungsten	Zinc	Lead	Molybdenum	Copper	Nickel	Average
Maximum	35	30	26	23	19	13	10	35
Minimum	58	50	47	39	53	36	25	22

Table 3

Metal reserves in processing tailings
Запасы металлов в хвостах обогащения

Loss, Mt							
Copper	**Zinc**	**Lead**	**Nickel**	**Al_2O_3**	**Molybdenum, t**	**Gold, Kt**	**Silver, Kt**
8,0	9,0	1,0	2,5	33,5	200	1	12

losses of technologically exposed metals (Table 2).

The tailings of flotation of non-ferrous metal ores in waste from industrial subsectors, which is used in the vast majority of cases, contain reserves equivalent to new deposits (Table 3).

Based on the results of the analysis of technologies involving metal leaching, their capabilities as a combination element are estimated by extraction ratio, %:

- underground leaching in blocks 50–60 for 1 year;
- leaching in stacks of 20–70 for 2–6 months;
- leaching in a disintegrator 20–70 for 1–5 minutes.
- The influence of the factor of combining traditional mining and processing technologies with leaching technologies consists of the following components:
- increasing the volume of production of commercial non-ferrous metals [24];
- increasing the competitiveness of domestic plants through import substitution with rare metals extracted during leaching;
- drastic improvement of the environment in the mining regions;
- return to production of land within the mine waste.

Conclusions

Intensification of the development of the resource base of metallurgy is carried out by combining mining and processing technologies with an increase in the recovery of valuable components from the extracted raw materials.

Issues of waste generation and storage, as aspects of the objective of the mineral resources sector development, are solved by combining traditional and new deposit development technologies.

Currently, there is a tendency to move from bulk extraction of various types of raw materials using powerful equipment to selective extraction.

The methods have been developed to evaluate palliative technological solutions associated with metal loss.

The method of leaching metals with the application of high energy in activators, for example, in a disintegrator, is being developed, making it possible to bring extraction to the level of sanitary standards from the liquidation of processing tailings storage facilities.

The effectiveness of combining traditional and innovative technologies is determined by the solution of the proposed model.

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