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ASSESSMENT OF ENVIRONMENTAL AND RESOURCE-SAVING TECHNOLOGIES AND TECHNICAL MEANS FOR PROCESSING AND DISPOSAL OF MAN-MADE FORMATIONS AND WASTE

Об'єктом дослідження є природоохоронні та ресурсозберігаючі технології та технічні засоби для переробки та утилізації техногенних утворень і відходів при підземній розробці родовищ корисних копалин із закладкою виробленого простору. Одним з найбільш проблемних місць є управління станом рудовміщуючих енергетично порушених масивів і доставка твердіючих закладних сумішей до місця їх укладання, а також дефіцит компонентів для їх приготування. Це підвищує важливість питань управління напружено-деформаційним станом (НДС) масиву гірських порід, забезпечення збереження денної поверхні від руйнування та життєдіяльності населення, що проживає в зоні впливу гірничодобувного регіону.

У роботі представлені основні наукові та практичні результати обґрунтування технологій та технічних засобів для утилізації відходів гірничо-металургійного виробництва в підземні вироблені простори (техногенні порожнечі) в якості компонентів твердіючих закладних сумішей різного складу та міцності. Описано методи теоретичних узагальнень із застосуванням математичної статистики, фізичного та математичного моделювання, з виконанням розрахунків і техніко-економічних обґрунтувань, лабораторних і натурних експериментальних досліджень, промислових випробувань в умовах діючих підприємств гірничо-металургійного виробництва. На основі дослідження механізму НДС масиву порід з використанням геофізичних і маркшейдерських методів запропонована природоохоронна технологія погашення техногенних порожнеч в енергетично порушених масивах. Дана технологія дозволяє забезпечити збереження денної поверхні та життєдіяльність населення, що проживає в зоні впливу гірничих об'єктів (шахти, відвали, промислові майданчики для закладних комплексів, хвостосховища, рудо-збагачувальні фабрики (РЗФ) та ін.). Встановлено, що для шахт державного підприємства «Східний гірничо-збагачувальний комбінат» (Україна) коефіцієнт використання відходів власного виробництва для твердіючої закладки становить від 0,45 до 0,68; гідравлічної – від 0,56 до 0,75; сипучої – 0,62, а видобуток кожної тони товарної руди супроводжується виходом 0,7–0,8 т відходів. Дана оцінка рівня утилізації відходів гірничо-металургійного виробництва та наведено кадастр для відходів гірських підприємств, який дає оціночну характеристику та напрямки можливого їх використання для потреб народного господарства. Результати досліджень можуть бути використані під час підземної розробки рудних родовищ складної структури та гірничо-металургійного виробництва.

Ключові слова: відходи гірничо-металургійного виробництва, природоохоронна та ресурсозберігаюча технологія, технічні засоби, життєдіяльність населення.

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1. Introduction

Extraction of mineral raw materials has a negative impact on the natural environment [1, 2]. The neutralization of this influence is achieved through nature and resource-saving technologies and technical means of mining [3, 4]. The authors refer to such technologies, first of all, various variants of development systems with filling of goaf with hardening filling mixtures of different composition and strength [5, 6]. However, their application is complicated by:

- the difficulties of managing the state of ore-containing energy disturbed massifs;

- transportation through the pipeline of the hardening filling mixtures over considerable distances vertically and horizontally to the place of their laying;
- increased material and labor costs;
- shortage of material for the preparation of mixtures [7, 8].

Therefore, the development of new methods, technologies and technical means for the integrated use of mining and metallurgical production wastes is a task of great commercial and social importance, requiring a prompt solution [9, 10]. This ensures the reliability of the transportation of the hardening filling mixtures through the pipeline, the safety of work, the possibility of using local substandard materials and production waste for filling. As well as reducing

the cost of extracting raw materials while preserving the earth's surface. This work is a continuation of research, the main scientific and practical results of which are most fully presented in [11, 12].

2. The object of research and its technological audit

The object of research is environmental and resource-saving technologies and technical means for the processing and disposal of man-made formations and waste in the underground mining of mineral deposits with backfilling of the goaf.

One of the most problematic areas is the management of the state of ore-containing energy-disturbed massifs and the delivery of hardening filling mixtures to the place of their laying, as well as the shortage of components for their preparation. This increases the importance of the management of the stress-strain state (SSS) of the rock mass, ensuring the safety of the day surface from destruction and the vital activity of the population living in the zone of influence of the mining region [13, 14].

3. The aim and objectives of research

The aim of research is to assess technologies and technical means for the disposal of man-made formations and waste of mining and metallurgical production in underground goaf (man-made voids) as components of hardening stowing mixtures of various composition and strength and a tailing dump.

To achieve this aim, the following objectives are solved:

1. To determine the main directions of waste disposal of mining and metallurgical production.
2. To assess the technological schemes of stowing complexes and the level of utilization of waste from mining and metallurgical production in the underground goaf as components of hardening stowing mixtures.
3. To develop a cadastre of mining and metallurgical waste and directions of their possible use for the needs of the national economy.

4. Research of existing solutions of the problem

The creation of environmental technologies is especially important for mining and processing enterprises of the raw material base of non-ferrous metallurgy and nuclear energy, which are among the industries with the highest yield of various wastes, including radioactive, per unit of finished product. Waste from mining (waste rock, off-balance ores in uranium content and tailings of heap leaching, which contain natural radioactive materials), are usually stored on the surface in dumps [15].

An analysis of the work of mining enterprises shows that during the extraction and primary processing of 1 ton of commercial uranium ore, 1.4–1.6 tons of waste are simultaneously extracted, creating an ecologically unfavorable environment for the region. Utilization of mining and metallurgical waste (laying of goaf, construction of dams of special storage facilities, etc.) allows using up to 50–60 % of their total volume, and the rest is subject to burial, decontamination and subsequent reclamation of contaminated areas. The problem of obtaining environmentally friendly materials

is especially important when using wastes that concentrate natural radionuclides that pose a danger to human health and the environment [16]. Such concentrators of radionuclides include waste from uranium, coal mining, heat and power and other industries. It is also of great importance to determine the radionuclide composition of waste fractions and their compliance with the radiation safety standards of individual countries [17, 18]. As well as the standards adopted by international radiological indicators [19].

Wastes from the processing industry of hydrometallurgical plants (HMP) are also natural radioactive materials with a particle size of 0.074 mm, which are transported through slurry pipelines and stored in special upstream storage facilities. In this regard, the problem of utilization of waste from mining and processing industries is acquiring an important national economic importance, especially in areas of fertile and densely populated lands [20].

The experience of mining enterprises shows that the waste of their production can be disposed of in the following main directions:

- as a filling material (in hardening mixtures and slurries, as well as loose filling) to fill the goaf formed in the course of mining operations;
- to fill the goaf, caving funnels, various ravines and gullies, followed by reclamation of the damaged surface;
- in the construction of dams, storage dams for storing waste with their subsequent reclamation;
- for the manufacture of crushed stone.

The most important measure for increasing the completeness of the extraction of reserves, protecting the subsoil and the environment during underground mining of ores is the transition to mining systems with backfilling of the goaf with hardening mixtures. The authors attribute the mining technology with hardening backfill to nature and resource saving. This is achieved primarily through the use of continuous mining of ore bodies, an increase in the floor height and parameters of the mining system. This technology is aimed at reducing ore losses in the pillars and bottoms of blocks, as well as increasing the possibility of advanced or separate breaking and extraction of ore. Reducing the loss of minerals during the extraction and processing of ores is achieved by reducing dilution and increasing the completeness of extraction of useful components at the limit. This measure allows to reduce the number of simultaneously mined deposits and focus on the most profitable of them, as well as to reduce the volume of exploration and mining operations.

The backfill technology is especially effective in areas with a protected surface of high-value lands in the extraction of rich and scarce ores, when the costs associated with backfill operations are offset by the above positive effect. In recent years, the use of hardening backfill in ore mining has increased dramatically. This is ensured by the results of targeted research on the search for new source materials for hardening filling mixtures, the selection of rational compositions and the improvement of the filling facilities of mining enterprises. However, when determining the compositions of the hardening backfill mixture, the factors influencing its properties are not fully taken into account, and cement or ground granular acidic slag with activating additives is mainly used as a binder. Today these materials have become scarce.

In the course of the study, the analysis of literature sources and patent documents in the field of technologies and technical means for the disposal of man-made forma-

tions and waste of mining and metallurgical production into underground goaf (man-made voids) and their storage in tailing dumps was carried out. This is provided due to the activation of the binder, substandard inert filler and electrochemically purified mine mixing water during their manufacture and transportation to the place of laying. Also by storing tailings after hydrocycloning and adding a hardener to tailings [21].

Thus, the results of the analysis allow to conclude that reducing the hazard to the environment by recycling ore raw material waste into the underground goaf solves important scientific, practical and social problems [22]. One of the issues that need to be addressed is the management of the state of ore-containing energy disturbed massifs and the delivery of hardening filling mixtures to the place of their laying, as well as the lack of components for their preparation. As well as management of the stress-strain state (SSS) of the rock mass, ensuring the safety of the earth's surface from destruction and vital activity of the population living in the zone of influence of the mining region. This is achieved due to environmental and resource-saving technologies in the underground mining of mineral deposits with backfilling of goaf of various composition and strength.

5. Methods of research

To solve the aim in the work:

- the analysis of literary sources is carried out;
- the method of theoretical generalizations with the use of mathematical statistics, physical and mathematical modeling is used;
- calculations and feasibility studies, laboratory and field experimental studies are made, as well as industrial tests in the conditions of operating enterprises according to standard and new methods [23].

6. Research results

6.1. Technological schemes of the filling complex. At the mines of the state enterprise «Vostochnyi Mining and Processing Plant» (SE «VostGOK», Zhovti Vody, Ukraine), technological schemes for the preparation of a hardening filling mixture on surface stationary filling complexes based on a binder made of granulated blast furnace slag and low-grade sand (Fig. 1).

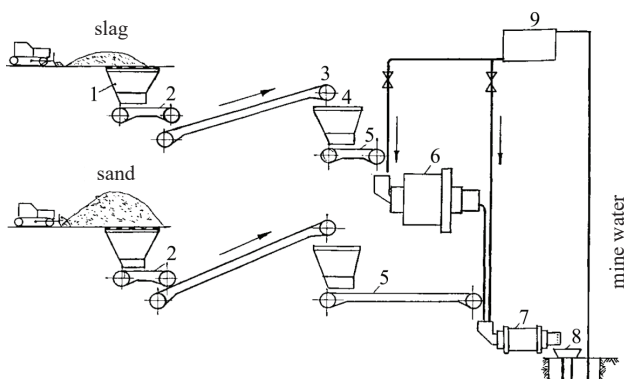


Fig. 1. Technological scheme of the filling complex:

- 1 – receiving hopper; 2 – feeder; 3 – conveyor; 4 – storage hopper;
- 5 – dispenser; 6 – ball mill; 7 – mixer; 8 – receiving funnel;
- 9 – container for mixing water

Sand and slag from the supply warehouse are transported by a bulldozer to the receiving hoppers, from where these materials are delivered by apron feeders, and then by belt conveyors they are delivered to intermediate hoppers and then to automatic belt dispensers. To separate lumps of clay and other impurities, the sand passes through a screening grate installed above the intermediate hopper. After dosing, the slag in a certain ratio with water enters the ball mill, and then in the form of a pulp into the mixer, where it is mixed with sand. The mixer is also supplied with water to give the filling mixture the desired mobility. The finished mixture enters the receiving funnel, then it is transported through pipes in a gravity-pneumatic mode to goaf.

Studies have established that heap leaching tailings or crushed rocks can be used as an additive to the filler of the hardening fill. Moreover, the strength of the artificial massif with the addition of heap leaching tailings is higher than with the use of crushed rocks at the same slag consumption per 1 m³ of filling. Preparation of heap leaching tailings and preparation of the hardening backfill mixture is carried out as follows (Fig. 2).

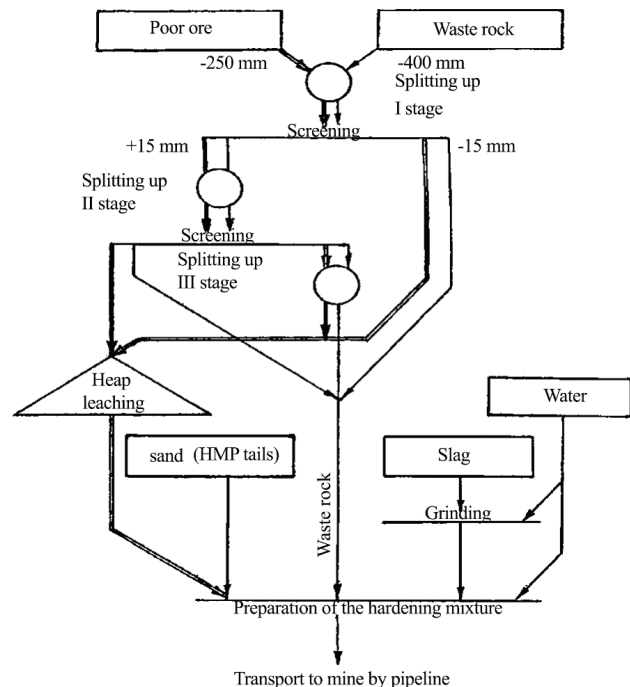


Fig. 2. Technological scheme for the preparation of a hardening backfill mixture based on the tailings of a hydrometallurgical plant or heap leaching tailings

After leaching and washing, the tailings are transported to the filling complex. At the same time, crushed rock is fed. The dosage is carried out in a certain ratio with the sand and enters the mixer, into which ground blast furnace slag and mixing water are fed in the required amount. The finished hardening backfill mixture is transported through the pipeline to the goaf. The analysis of the technology for the construction of artificial massifs from the hardening filling mixture that in the conditions of the mines of the State Enterprise «VostGOK» the use of waste from mining and processing industries is technically feasible in two ways.

The first one is centralized, based on the preparation of a hardening filling mixture at a stationary filling complex

and supplying it in a finished form to the place of laying through pipelines. It is distinguished by its simple organization and high reliability of stowing operations. However, large costs are required for the construction of a crushing and screening complex for crushing rocks.

The second is separate, which includes feeding the hardening backfill mixture and coarse aggregate separately and mixing them when laying directly into the goaf. The main advantage of this method is the possibility of using stowing materials of any size, and the disadvantage is the need to create an additional mechanized chain to deliver rocks to the pledged chamber, the formation of oncoming cargo flows, and the complexity of organizing stowing operations. Taking into account the best manufacturability, industrial reliability, a stowage work scheme was adopted, which allows the use of crushing and screening complexes of a stowing plant for crushing rocks and off-balance ores sent for heap leaching (Fig. 3).

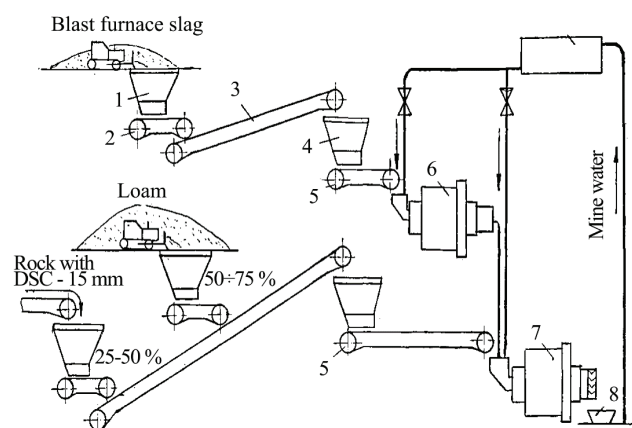


Fig. 3. Technological scheme of a filling complex for preparing a hardening filling mixture using crushed rocks and heap leaching tailings: 1 – receiving hopper; 2 – feeder-dispenser; 3 – conveyor; 4 – consumable hopper; 5 – dispenser; 6, 7 – ball and rod mills, respectively; 8 – receiving funnel; 9 – water tank

The authors have studied the properties of the hardening filling mixture prepared on the basis of mining and metallurgical waste and ground granulated blast furnace slag for the conditions of the mines of the SE «VostGOK». It has been established that all waste is suitable for the preparation of a hardening filling mixture as a filler. The presence of sulfate ions in the HMP tailings does not affect the strength of the fill and does not reduce its strength. On the basis of mining and metallurgical waste and ground granulated blast furnace slag, complex compositions of the hardening filling mixture have been developed [24]. Analysis of the compositions of the hardening backfill mixture shows that the use of this technological scheme makes it possible to reduce the consumption of a scarce expensive binder - ground granulated slag by 2–2.6 times (from 400 to 150 kg/m³). As well as the unit costs for laying almost 2 times, but the main thing is to dispose of radioactive waste into underground voids.

The density of the filling mass is 2100–230 kg/m³. Studies have shown that 40 % of the volume of underground voids formed in the course of mining operations can be repaid with a hydraulic mixture or free-flowing backfill. In this case, completely separate isolated waste blocks and the upper parts of the chambers of the second

stages of the excavation are extinguished [25]. Feasibility studies have shown that, taking into account the existing production technology and delivery to the place of laying the filling material, the most rational scheme is the crushing of rock waste and their transportation through pipelines to underground voids.

Such a scheme is characterized by simplicity of organization and maintenance, high performance and reliability in operation. The optimal size of the waste is determined taking into account the costs of crushing, pipeline transport and the density of their placement in the spent chambers and is in the range of 25–35 mm. However, the large-scale introduction of this technology is hampered by the strong wear of the backfill pipelines, especially in vertical and curved sections, and the pipelines require special coatings, for example, basalt [26].

At present, overburden clay sands are used instead of HMP tailings as a fine aggregate in the composition of the hardening filling mixture. This is due to the fact that today there are no safe, reliable and cheap means of transporting dusty radioactive waste over long distances, and especially the technology for preparing, transporting and placing in the chamber a solidifying filling mixture based on HMP tailings.

To substantiate the suitability of low-grade sands of the local Oboznovskyi quarry (Ukraine) as a filler in the composition of the hardening filling mixture for the mines of SE «VostGOK», the authors carried out studies of their characteristics, mobility and strength properties. For this, in accordance with the current methods, the strength properties of the hardening filling mixture were determined in time, using these sands, ground granulated slag and mixing water. Based on 1 m³ of the mixture, the consumption of ground granulated slag is 230–365 kg, the fineness of its grinding does not exceed 55 %, the content of particles is 0.074 mm, the mobility of the hardening filling mixture is 12–12.5 cm, measured by a solution density device (SDD) by the cone of «StroyTSNIL» (Ukraine) was provided with a mixing water flow rate of 425–465 liters.

The sand size modulus of all samples corresponded to the set technical requirements and varied within the range of 0.46–2.31. In some samples taken from the lower intervals of the wells, there are not enough clay particles, their content is in the range of 5.4–23.0 %. Some sand samples have an increased content of organic impurities. The noted disadvantages can be eliminated by mixing the sands of the upper and lower horizons in the process of their extraction. The strength of the hardening fill, obtained on the basis of the sands of the Oboznovskyi quarry (Ukraine), is 3.2, 5.3 and 6.4 MPa after hardening, respectively, 90, 180 and 360 days, with the consumption of ground granulated slag 313 kg per 1 m³ of the mixture. The influence of clay and organic matter on the strength of the fill was not observed. After placing the filling mixture into molds, its solid particles are compacted, squeezing out excess mixing water, thereby increasing its density and consumption of starting materials. The coefficient of compaction of the hardening filling mixture is determined by the formula:

$$k_y = \frac{\gamma_m}{\gamma_c} = \frac{1.715}{1.495} = 1.15, \quad (1)$$

where γ_m , γ_c respectively, the mass of solid material in the massif and the initial, kg/m³.

To ensure the required strength of the hardening filling of 3 and 5 MPa, the consumption of ground granulated slag per 1 m³ of the mixture is, respectively, 283 and 384 kg in the massif and 246 and 303 kg in the hardening filling mixture. On the basis of the obtained research results, the sands of the Oboznovskyi quarry in their quality are close to the sands used from the Morozovskyi quarry (Ukraine), provide the specified strength of the filling mixture and its satisfactory transport through pipelines to the place of laying. The recommended required strength of the hardening insert 5.0 and 3.0 MPa is provided by the composition per 1 m³ of the mixture: respectively, sand 1200 and 1250 kg, the main granular slag 300 and 250 kg, mixing water (for two compositions) varies from 400 to 450 l. In the backfill mass, these indicators are: sand 1365 and 1435 kg, the main granular slag 350 and 280 kg.

6.2. Assessment of the level of waste disposal in mining and metallurgical production. It is produced according to the indicators of their output per 1 ton of commercial ore and the use to fill the goaf, according to the formulas:

$$k_{u.r.} = \frac{P_r}{\gamma_r}, \quad (2)$$

$$k_{u.t.} = \frac{P_t}{\gamma_t}, \quad (3)$$

$$k_{u.w.} = \frac{(P_r + P_{ob.} + P_t + P_{th.})}{\gamma_o}, \quad (4)$$

where $k_{u.r.}$, $k_{u.t.}$, $k_{u.w.}$ – accordingly, the coefficients of using rocks, tailings and waste to fill the goaf, fraction of units; P_r , P_t – respectively, weight of rock and tailings per 1 m³ of fill in the massif, t/m³; γ_r , γ_t – respectively, the density of the rock and tailings (source material) in the massif, m/m³; $P_{ob.}$, P_t , $P_{th.}$ – respectively, the weight of off-balance sheet, in terms of the content of the useful component, ore, heap leaching tailings and tailings of hydrometallurgical processing, t/m³; γ_o – ore density, t/m³.

The density of the hardening filling mixture with additions of crushed material is determined according to the formula:

$$\gamma_h = \gamma_s + P_{cr.} \left(\frac{1 - \gamma_s}{\gamma_r} \right), \quad (5)$$

where γ_h – density of the hardening filling mixture with additives of crushed rocks, kg/m³; γ_s – density of the

hardening sand-slag filling mixture, kg/m³; $P_{cr.}$ – weight of the crushed rock additive, kg/m³.

For mining enterprises of SE «VostGOK» the coefficient of use of own production wastes in the hardening backfill is from 0.45 to 0.68; hydraulic – from 0.56 to 0.75; free-flowing – 0.62.

6.3. Development of cadastre for mining and metallurgical waste. On the basis of the research carried out, the authors have developed a cadastre for mining and metallurgical waste, which gives an estimated characteristic and directions of their possible use for the needs of the national economy (Table 1). Disposal of solid waste from mining and metallurgical industries is carried out as follows. Waste rocks are separated from the current and stored in dumps of rock waste and used in construction, taking into account the requirements of radiation safety standards. Off-balance ores and tailings of the radiometric concentration plant are sent to the underground goafs according to the existing technology at the mining enterprise for further leaching of ore-containing materials in the spent chambers [27]. The rest of the solid waste is transported and deposited in the internal dumps of existing local operating or spent open pits, after which the disturbed area is covered with overburden and reclaimed.

At a number of mines in developed mining countries of the world, stowing complexes have been created for the preparation of hardening stowing mixtures, and at some of them – local binder from blast-furnace slag, crushing and screening complexes for processing rock waste into crushed stone, greenhouses, etc. mining enterprises, the equipment of these complexes can be effectively used for the production of building products and structures [28].

At the mines of the SE «VostGOK» the existing filling complexes can be used for the production of cinder blocks, concrete blocks for foundations and other building products. At the same time, from the imported granulated blast-furnace slag in operating ball mills, it is possible to obtain a local binder – slag-alkaline cement, and at the crushing and screening complex – own crushed stone from waste rocks. This will ensure the employment of workers released from the mining industry and receive additional funds for the conversion of stowing facilities into construction shops [29].

The construction of dams made from waste from mining and processing industries for storage facilities have been widely studied and worked out. There are normative and technical documents, which indicate the most appropriate compositions of waste and binder compositions, methods, techniques and technology for their transport and stacking.

Table 1

Cadastre of solid waste of mining and metallurgical production

Waste	Size, mm	Source of receipt	Waste yield from the total volume of rock mass, %	Direction of possible use
Waste rock (lumpy)	–350 (–500)	Mining capital workings	3–4	Construction material
Off-balance ore (lumpy)	–350 (–500)	Mining preparatory and grooved workings	10–12	Filling raw materials, partly building materials
Also	–350 (–500)	Cleaning workings	3–5	Filling raw materials after processing
Also	+50–250	Sorting at an ore-processing plant (OPP)	20–30	Also
Sandy	–0.5+0.043	Hydrometallurgical processing of commercial ore	17–22	Stacked raw materials, partially sent to the tailing dump
Muddy	–0.043			

Special complexes are proposed for dewatering the HMP tailings, preparing a hardening mixture from them and a binder, and the subsequent construction of dams. The complex for preparing tailings for storage consists of a dewatering building, warehouses for dewatered tailings and cement, a solution preparation unit, thickeners, conveyor galleries and auxiliary structures [30]. Waste from the HMP is transported to the storage facility via a slurry pipeline.

6.4. Implementation of research results. New technological schemes of stowing complexes for disposal of mining and metallurgical waste into an underground goaf as components of hardening stowing mixtures have been proposed. The scheme of «dry» immobilized storage of solid wastes of mining and metallurgical production in a bulk instead of the traditional bulk method is also recommended. They show positive results in underground mining of ore deposits of complex structure in the Russian Federation, the North Caucasus, Ukraine, North Kazakhstan and other developed mining countries of the world [31]. Scientific, design and technological support for the development of these developments was carried out by the State Enterprise «Ukrainian Research and Design Institute of Industrial Technology», which in 2020 celebrated its 50th anniversary. Scientific and production support – Scientific and production complex «Automation and Mechanical Engineering» (Ukraine) together with the Repair and Mechanical Plant (Ukraine) [32].

6.5. Promising areas of research. The ecology of mining is still developing along the way of managing the process of formation of man-made deposits in the course of the development of deposits and the conversion of inactive reserves of man-made deposits into active ones by influencing them by physicochemical processes. In addition, it is necessary to develop scientific and methodological foundations, technologies and technical means to increase the fertility and efficiency of soil use in industrial zones of mountain facilities, as well as assess their impact on the environment and humans, taking into account the long-term consequences [33].

The difference between the combined mechano-chemical activation of metal-containing raw materials is that the leaching reagent is supplied to the disintegrator working body, and the extraction of metals into the solution occurs simultaneously with the destruction of crystals, when the solution is intensively pressed into the resulting cracks.

The most promising is the method for extracting metals from the tailings, which involves combining the processes of chemical enrichment and activation in a disintegrator. This ensures the extraction of metals into the solution simultaneously with the destruction of crystals, when the leaching solution is intensively pressed into the cracks formed from the disintegration of particles. The disadvantage of this method is the incomplete extraction of useful components in the case of processing refractory non-oxidized ores due to insufficient chemical activity of the latter.

7. SWOT analysis of research results

Strengths. On the basis of the substantiation of technologies and technical means for the disposal of mining and metallurgical production waste into the underground goaf, a complex of technical means for activating the components

of hardening filling mixtures is proposed. Environmental and resource-saving technologies for underground mining of mineral deposits with backfilling of goaf provide:

- safety of objects of operation;
- safe mining;
- completeness of use and protection of subsoil and the environment;
- vital activity of the population living in the zone of influence of mountain objects.

Weaknesses. The main negative impact of mining technology on the environment and humans is the high cost of preserving the day's surface and ensuring the livelihoods of the population living in the zone of influence of mountain objects, withdrawing large areas of land from use, etc. [34]. Therefore, it is necessary to provide funds for the following activities:

- deep processing of man-made waste (tailings), which has a wide variety of mineral forms in comparison with conventional ores;
- reclamation of the territory of industrial sites and the territory adjacent to them after the end of operation;
- landscaping of the reclaimed territory with grass and shrub vegetation;
- constant monitoring of environmental components in the zone of influence of mountain objects.

Opportunities. When delivering hardening filling mixtures into man-made cavities over a long distance and a shallow depth of mining operations, the most promising is vibro-gravity transport, which provides homogenization of the mixture and an increase in strength due to their activation in the pipeline. The wide involvement in the production of man-made reserves of ore dressing tailings, as well as the processing of off-balance dumps, in terms of the content of useful components, ores in modular installations contribute to obtaining an additional source for the industry in metals [35].

Threats. To prevent the dust transfer of contaminated material outside the mountain objects, it is advisable to plant sanitary protection zones and strips around them with tall tree species that will restrain the wind speed over the specified objects. These include mines, waste rock dumps and off-balance ores in terms of the content of the useful component, stowing complexes, sites for pre-concentration and heap leaching of metals from substandard ore raw materials, tailings, etc. In this case, dust will settle in these forest plantations and will not enter other territories, including in settlements. In addition, it is necessary to develop scientific and methodological foundations, technologies and technical means to increase the fertility and efficiency of soil use in industrial zones of mountain objects, as well as assess their impact on the environment and humans [36].

To continue research on the detection of natural radionuclides: ^{226}Ra , ^{232}Th and ^{40}K in the composition of fuel ash and slag and waste rocks of uranium, coal mining, heat power and other industries. The content of radionuclides varies by waste fractions. The main contribution to the effective specific activity of waste is made by ^{226}Ra and ^{232}Th . The largest scatter of specific activities in the fractions of these coal-mined rocks is typical for ^{226}Ra . All studied wastes belong to the first class of radiation hazard and can be used in construction without restrictions. According to international radiological indicators, the value of the activity utilization index was exceeded for almost all studied wastes [37].

8. Conclusions

1. The main directions of waste disposal of mining and metallurgical production (laying of goaf, construction of dams of special storage facilities, etc.) have been determined, which allow using up to 50–60 % of their total volume, and the rest is subject to burial and subsequent reclamation of contaminated areas.

2. It was found that for the mines of the State Enterprise «VostGOK» the coefficient of use of own production waste in the hardening backfill is from 0.45 to 0.68; hydraulic – from 0.56 to 0.75; free-flowing – 0.62, and the extraction of each ton of commercial ore is accompanied by the output of 0.7–0.8 tons of waste.

3. A cadastre of mining and metallurgical production wastes has been developed, depending on their size, source of production, output from the total volume of rock mass and the direction of possible use for the needs of the national economy. Thus, the yield of waste from the total volume of the rock mass in % from mining capital, mining preparatory, rifled and cleaning workings is, respectively, 3–4, 10–12 and 3–5 %, and from sorting at the OPP and hydro-metallurgical redistribution of ore, respectively, 20–30 and 17–22 %.

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