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SUBSTANTIATION OF TECHNOLOGIES AND TECHNICAL MEANS FOR DISPOSAL OF MINING AND METALLURGICAL WASTE IN MINES

Об'єктом дослідження є природоохоронні та ресурсозберігаючі технології при підземній розробці родовищ корисних копалин із закладкою виробленого простору. Одним з найбільш проблемних місць є доставка закладних сумішей, що тверднуть, до місця їх укладання та дефіцит компонентів для їх приготування. Це підвищує важливість питань управління станом масивів, що містять руду, та збереження земної поверхні.

У роботі представлені основні наукові та практичні результати обгрунтування технологій та технічних засобів для утилізації відходів гірничо-металургійного виробництва в підземні вироблені простори (техногенні порожнини) в якості компонентів закладних сумішей, що тверднуть. Описано методи теоретичних узагальнень із застосуванням математичної статистики, фізичного та математичного моделювання, з виконанням розрахунків і техніко-економічних обгрунтувань, лабораторних і натурних експериментальних досліджень, промислових випробувань в умовах діючих підприємств. Встановлено, що застосування вібро-, механо- та електроактивації компонентів закладної суміші, що твердіє, на гірничих підприємствах призводить до підвищення активності некондиційних матеріалів на величину до 10–40 % для кожного апарату. Зокрема, збагачення некондиційних інертних матеріалів на вібр质гуркоті ГВ-1,2/3,2 (Україна) збільшує активність на 15–20 %. Обгрунтовано, що активація в'яжучих матеріалів (доменних гранульованих шлаків) у дезинтеграторі ДУ-65 (фірма «Дезинтегратор», Естонія) збільшує активність в'яжучого на 20–25 %, при виході активного класу фракцій розміром 0,074 мм – на 55 % проти 40 % в кульових млинах. Рекомендовані вібротранспортні установки, які збільшують активність твердих компонентів закладної суміші, що твердіє, на 10–15 %, а електродіалізні апарати для активації води затворення збільшують її активність на 30–40 %. Показано, що застосування установок вібросамопливного транспорту забезпечує подачу закладної суміші на відстань, що перевищує в 15–20 разів висоту вертикального ставу. Запропоновано комплекс технічних засобів для активації компонентів закладних сумішей, що тверднуть (в'яжучого, інертного заповнювача та електрохімічно очищеної шахтної води замішування), при виготовленні та транспортуванні їх до місця укладання. Даний комплекс впроваджено на таких гірничих підприємствах, як:

– Державне підприємство «Східний гірничо-збагачувальний комбінат» і Балаклавське рудоуправління (Україна);

– Акціонерне товариство «Цілинний гірничо-хімічний комбінат» (Республіка Казахстан);

– Публічне акціонерне товариство «Приаргунське виробниче гірничо-хімічне об'єднання імені Є. П. Славського» та Закрите акціонерне товариство «Уралзолото» (Російська Федерація) та в інших розвинених гірничодобувних країнах.

Ключові слова: *підземна розробка, суміш, що твердне, трубопровідний транспорт, вібро-, механо- та електроактивація компонентів.*

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1. Introduction

During underground mining, from 40 to 80 % of the formed man-made voids are filled with hardening filling mixtures. In most cases, hardening filling mixtures contain 0.1–0.35 dispersed particles with a concentration of solid particles in water of 0.10–0.85 and a draft of a standard cone of 10–13 cm is transported by gravity. Its capabilities also depend on the ratio of the vertical and horizontal components of the filling pipeline and for deep mines and mines do not exceed 1,500 m. In the gravity-pneumatic method, hardening filling mixtures move by gravity first, and then are delivered by compressed air to the place of their laying. Both methods are applicable when the ratio of the vertical and horizontal parts of the filling pipeline is at least 1/5 [1]. Therefore, the improvement of technologies and technical means for transporting hardening filling mixtures to mines is an important scientific, practical and social task [2]. This work is a continuation of research, the main scientific and practical results of which are most fully described in [3, 4].

2. The object of research and its technological audit

The object of research is environmental and resource-saving technologies in underground mining of mineral deposits with the laying of the developed space. One of the most problematic places is the delivery of hardening filling mixtures to the place of laying and the shortage of components for their preparation. This increases the importance of managing the state of ore-bearing massifs and the preservation of the earth's surface.

3. The aim and objectives of research

The aim of research is the justification of technologies and technical means for the disposal of waste from mining and metallurgical production into the underground mined space as components of hardening filling mixtures. At the same time, given the technological processes of activation of a binder, substandard inert aggregate and electrochemically purified mine mixing water during the manufacture and transportation of them to the installation site.

For the study, the following objectives are set:

1. To perform mathematical and physical modeling, as well as the calculation of the parameters of gravity transport, pneumatic transport and vibration gravity transport of hardening filling mixtures.
2. To develop technical means for gravity transport, pneumatic transport and vibration gravity transport of hardening filling mixtures.
3. To recommend vibration transport units to increase the activity of solid components of the hardening filling mixture.
4. To propose a new set of technical means for activating binder (blast furnace granulated slag), inert aggregates (product of screening of substandard materials) and mixing water in the manufacture and transportation of hardening filling mixtures.

4. Research of existing solutions of the problem

The mining-geological and hydrogeological conditions of rock deposits are best suited to chamber systems of mineral exploitation with filling the worked-out space with a hardening mixture. They are used in the development of steeply falling ore deposits with an angle of incidence of more than 50° and a thickness of 3 to 100 m in stable rocks with a Protodyakonov coefficient of strength of at least 12 [5]. They also occupy priority positions and to a greater extent ensure the safety of operating facilities, safe mining operations, full use and protection of the subsoil and the environment [6].

The main criterion for the effectiveness of mineral extraction technologies is the cost of a unit of metal, which is determined, inter alia, by the value of hardening filling mixtures. Therefore, the directions of reducing the cost of mixtures through the use of new technologies and internal production reserves are promising [7]. Although engineering measures somewhat improve the quality of hardening filling mixtures based on the use of available substandard raw materials. However, new technologies and technical means for utilization of mining and metallurgical production wastes into underground mined spaces as components of hardening filling mixtures are still developing at an insufficient pace [8]. Wastes from mining and metallurgical and related industries often play the role of inert aggregates, which is economically unjustified, given the possibility of using this raw material for the production of marketable products, for example, the same cement. A real possibility of changing the properties of utilized waste is provided by technologies for increasing their activity by mechanical and other treatment [9].

The authors perform an analysis of literature and patent documentation in the field of tailings storage after hydrocyclone and hardener additives in tailings [10, 11]. As well as laboratory and production experiments, physical modeling and selection of compositions of hardening mixtures according to standard and new methods [12, 13].

Thus, the results of the analysis allow to conclude that reducing the environmental hazard by utilizing waste from the processing of ore raw materials into underground space solves important scientific, practical, and social problems [14, 15]. This is achieved through environmental and resource-saving technologies in underground mining of mineral deposits with the laying of the developed space of various composition and strength. One of the most problematic places is the lack of components for the preparation of hardening filling mixtures and transportation to the place of their laying. This increases the importance of the creation and implementation of a set of technical means for activating binders, inert aggregates and mixing water during the manufacture and transportation of hardening filling mixtures to the place of their laying.

5. Methods of research

To solve this goal, the authors perform an analysis of literary sources, used the method of theoretical generalizations using mathematical statistics, physical and mathematical modeling. The calculations and feasibility studies, laboratory and full-scale experimental studies, as well as industrial tests in existing enterprises using standard and new methods are done [16, 17].

Vibration gravity transport units (hereinafter referred to as VTU) supply hardening mixtures to a distance significantly exceeding the height of the vertical stand. In the mines for the mining of uranium ores of Thuringia and Saxony of the former Soviet-German Joint-Stock Company (SGJSC) Wismut [18], a hardening mixture with StroiTsNIL cone sediment of 8.0 cm was fed to a distance 3 times the height of the vertical stand of the filling pipeline. The VTU of hardening filling mixtures at the Shokpak-Kamyshove ore deposit (Republic of Kazakhstan) included the vertical rates of the general and horizontal pipelines (Fig. 1) [19].

Hardening filling mixtures were supplied in portions of up to 400 m^3. Features of the transportation process included resistance to transportation in the cascade section, the use of low-activity aggregates with clay contents of up to 50 % and hard binder blast furnace granulated slag activated in the disintegrator. The sectionalized section of the pipeline was mounted on rubber shock absorbing supports, and sections of the pipeline 200 m long were equipped with vibration exciters. Under the influence of vibration, the mixture acquired a state of increased fluidity [20].

The simulation was carried out with a stepwise action and a constant pump speed of 1300 rpm. At the first stage (120 s), the stabilizing tank is filled. The second

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stage (up to 270 s) is characterized by a transient process of filling the pipeline with hydraulic mixture. At the third stage, the flow of the slurry is not limited, as a result of which its flow rate is redistributed. The main parameters of vibration delivery are: transportation length (L), height of the vertical pipe stand (N), section length (L_1) and the location of the vibration exciter within the section (L_2) (Fig. 2).

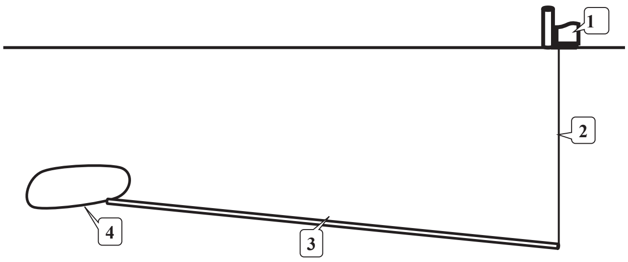

Fig. 1. Scheme of the vibration gravity pipe transport of hardening filling mixtures: 1 – filling complex with a capacity of 100 m^3/h; 2 – filling well 170 m long; 3 – cross heading 2.5 km long with a slope of 7°; 4 – ore body

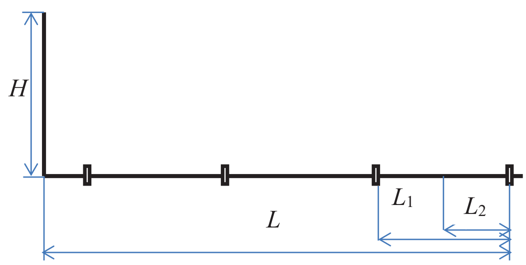

Fig. 2. Scheme of pipeline vibration transport of hardening filling mixture

Stratification of the mixture is excluded at a speed of its movement V=0.5–0.7 m/s for mixtures with aggregate size up to 5.0 mm and 0.7–1.0 m/s for mixtures with aggregate size 5.0–40.0 mm. The pressure loss during the movement of hydraulic mixtures is determined for different density of the mixture. The hydraulic resistance parameters are determined by the least squares method (Table 1).

Table 1

Dynamics of hydraulic resistance

Sample	Density, t/m^3	Hydraulic resistance (I)
1	1.00	$100I = 4.334V^2 + 2.158V$
2	1.11	$100I = 4.819V^2 + 2.323V$
3	1.13	$100I = 4.923V^2 + 2.347V$
4	1.19	$100I = 5.199V^2 + 2.385V$
5	1.22	$100I = 5.308V^2 + 2.523V$
6	1.26	$100I = 5.577V^2 + 2.384V$
7	1.32	$100I = 5.726V^2 + 2.747V$
8	1.40	$100I = 6.029V^2 + 3.007V$

With an increase in the flow rate of the hardening filling mixture in the pipeline, the losses naturally increase, and the values of the pressure losses obtained by calculation and experimentally practically coincide (Fig. 3). Values of critical velocities differ from experimental values by up to 34 %. Delivery performance A (t/h) depends on the fineness of the components of the hydraulic mixture Q (%), on the maximum value for these conditions (Fig. 4).

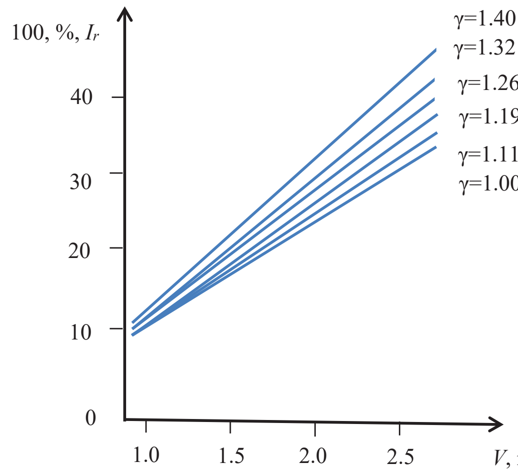

Fig. 3. The graph of the pressure loss on the flow rate of the hardening filling mixture

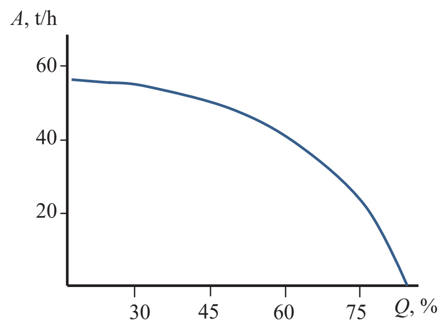

Fig. 4. The dependence of the performance of the filling complex A on the size of the components of the hydraulic mixture Q

In order to verify and confirm the main analytical expressions, conclusions, as well as a quantitative substantiation of the VTU efficiency with circular driving force when feeding the mixture into the worked out space, experimental studies were conducted in laboratory and industrial conditions. To solve the problems posed, the productivity of the shock wave was determined depending on the direction of action of the driving force B of the vibration exciter, the frequency of the forced vibrations f, and the values of vibration acceleration $A\omega^2$. Research conducted on a laboratory bench. The composition of the hardening filling mixture per 1 m^3: granulated blast furnace slag – 400 kg, sand – 1200 kg, water – 400 l, standard cone sludge – 11.5 cm. The composition of the mixture was changed so that the standard cone sludge was 10–13 cm.

The measurement of the acceleration of the pipeline was performed using acceleration sensors DU-5 (Russian Federation), which are included in the set of vibration measuring equipment VI6-5MA (Russian Federation). The measurement results are presented in graphs (Fig. 5). The maximum VTU performance is achieved with: circular driving force of the vibration exciter (curve 1 in Fig. 5, *b*), vibration acceleration at the location of the vibration exciter $A\omega^2 = (0.6–0.9)g$, vibration frequency f=14–18 Hz and vibration amplitude Ay=1.0–1.5 mm. To ensure a stable position of the VTU pipeline, supports were used in which two elastic cylindrical elements were installed. The axis of the elastic elements is located vertically. The maximum value of the VTU performance was obtained with the ratio of the stiffnesses of the elastic element in the horizontal and vertical planes C_x/C_y=1.2–1.4.

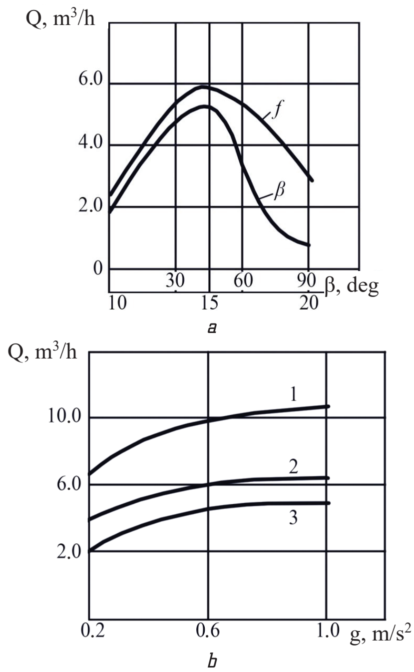

Fig. 5. The dependence of the VTU performance (vibration transport unit): *a* – direction of action of the driving force of the vibration exciter and the frequency of the forced vibrations; *b* – vibration accelerations: with circular 1 and directed driving force at β=30° and β=0°, respectively, 2 and 3

To determine the effect of the method of delivering a hardening filling mixture to the worked out space and the concentration of solid on the strength of the artificial mass in laboratory and industrial conditions, studies were conducted in which the amount of water and clay was changed. The research results are presented in graphs (Fig. 6). An analysis of the results shows that the maximum strength of the artificial massif is achieved when the concentration of solid K=0.80–0.85 and vibration gravity method of its transportation. The main scientific and practical results of increasing the activation efficiency of the components of the hardening filling mixture in VTU are most fully described in [21, 22].

An analysis of the results shows that the maximum strength of the artificial massif is achieved when the concentration of solid K=0.80–0.85 and vibration gravity method of its transportation. The main tool for activating the ingredients of the hardening mixture is a disintegrator, which, when exposed to a substance, creates an impact speed an order of magnitude greater than in vibration and ball mills and an acceleration of millions of free fall accelerations [23].

Experimental technology is characterized by a combination of activators of mechano-, vibro- and electrochemical or other types. This technology includes vibroactivation of inert aggregates on a vibrating screen, slag additive in a disintegrator and vibratory mill, mixing water in an electrochemical processing unit, and vibration of a hardening filling mixture during transportation (Fig. 7).

The technological scheme of the filling complex with the disintegrator-activator DU-65 (Disintegrator company, Estonia) and the vertical vibration mill MVV-0.7 (Ukraine), also includes a slag warehouse, cement tank, conveyor, mixer, wells and a filling pipeline for supplying hardening mixture into the mined-out space of the chambers. Disintegration technology provides an increase in the activity of binders by up to 40 % [24].

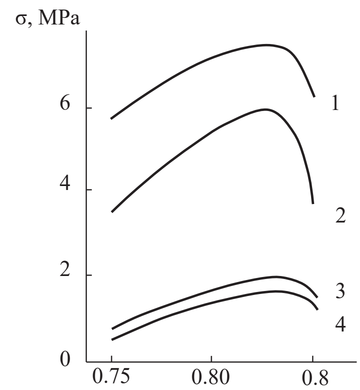

Fig. 6. The dependence of the strength of the artificial massif (σ) on the concentration of solid (K) and the method of delivery of the mixture: 1 – vibration gravity and 2 – gravity delivery methods with a clay content of 10 % by weight of aggregate; 3, 4 – vibration gravity when the clay content of the aggregate mass of 30 % and 40 %, respectively

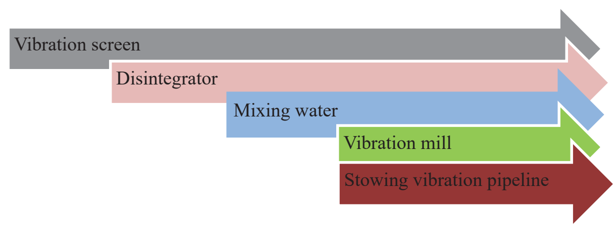

Fig. 7. The scheme of integration of activators in the manufacture and transportation of hardening filling mixtures

The experimental development of new technologies for the activation of the components of hardening mixtures during underground ore mining was carried out at the Joint-Stock Company «Tselinnyi Mining and Chemical Combine» (JSC «TsMCC», Stepnogorsk, Republic of Kazakhstan). The results allow to conclude that the combination of activation methods of the ingredients of the mixture has several advantages, the main of which are:

– possibility of increasing the raw material base;
– increase the coefficient of completeness of subsoil resources;
– ability to deliver the mixture to a distance significantly exceeding the limit for traditional technologies. This allows to abandon the construction of new filling complexes. The effectiveness of the preparation and transportation of hardening mixtures over long distances is determined by the interaction of not only known factors, but also by the imposition of an activation factor on them. When using the new technology, the completeness of the use of subsurface resources is increased, land for agricultural production is saved, and the environmental load is reduced due to the elimination of the danger of storing chemically hazardous tailings of metal ore dressing [25].

6. Research results

6.1. Vibration intensification of hardening mixtures. At mining enterprises such as Eastern Mining and Process-

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ing Plant State Enterprise Eastern Mining and Processing Plant (Zhovti Vody, Ukraine), which develop ore deposits, the method of filling the worked out spaces with a hardening filling mixture based on ground granulated slag from the Kryvyi Rih Metallurgical Plant is widely used (Public Joint Stock Company ArcelorMittal Kryvyi Rih, Ukraine) [26]. Its composition per 1 m^3 of the mixture: slag – 250–400 kg, sand – 1200–1350 kg, mixing water – 300–450 l, depending on the strength of the bookmark in compression.

At mining enterprises of JSC «TsMCC» ore deposits are mined by chamber systems with a hardening tab [27], where the following are used:

– Karaganda blast furnace slag, fly ash of coal from the Kansk-Achinsk basin, ferrochrome slag from the Aktobe Ferroalloys plant, phosphogypsum from the Voskresensk Association and the Frunze TPP (thermal power plant), Republic of Kazakhstan;
– fly ash of Reftinskaya thermal (condensation) state district power station (State District Electric Power Station), Russian Federation. The fundamental possibility of using cheap binders as binders has been proven, but industrial blast-furnace slags have so far been used mainly.

An important component of a monolithic bookmark is its rigid filler base. Aggregate affects the strength and transport quality of the bookmark. Known materials that are applicable for the preparation of hardening filling mixtures: natural sands and gravel, dump rocks, tailings of OPP (ore processing plant), slags of metallurgical production, however, despite the country's rich mineral resources base, the number of standard aggregates does not satisfy production requirements. This is reinforced by the high cost of transportation [28].

An indispensable component of the hardening filling mixture is water for mixing. The increased acidity of the water slows down the setting reaction, leaches the cement and neutralizes its chemical activity.

The use of non-standard small clay-containing (up to 30 %) sands for the preparation of hardening filling mixtures is associated with an increase in the consumption of binders. The use of mine water for mixing cement stone prevents the manifestation of the properties of the components of the hardening filling mixture. These disadvantages are eliminated in the preparation of the starting materials by their activation in the apparatus.

The choice of a rational solution to the modes and apparatuses of activation reduces the consumption of binders and the cost of filling technology. For the hardening filling mixture, the fineness of slag grinding has a significant effect on the strength of the artificial massif. With the same binder consumption, the strength of control samples in which the fineness of slag grinding was 88 % in class is 0.074 mm 5 times more than with fineness 50 %.

The presence of bonded materials in the hardening filling mixture worsens the conditions for the formation of artificial arrays. Deviations for these reasons from the mode of preparation, transportation and placement of the mixture cause delamination in the pipeline. Therefore, in the manufacture of low-strength bookmarks with a compressive strength of up to 1.2 MPa, it is necessary to ensure fineness of grinding, the destruction of loosely bound pieces of aggregate and a stable mode of transportation. This is done by vibroactivation of inert materials, mechanically activating binders before mixing, vibroactivating a hardening filling mixture during its transportation and electrochemical activation of water [29].

The mechanical activation of binders is carried out in grinders, for example, the most common ball mill MB 3200×4500 (Russian Federation). However, high-speed devices are most effective, for example, DU-65 disintegrator activators and a vertical vibration mill MVV-0.7.

At the mining enterprises of JSC «TsMCC» vibration, mechanical and electrochemical activation apparatuses were used to obtain a hardening filling mixture with a strength of up to 1.2 MPa, using low-grade materials.

Non-standard sands, cement, slag and mine water was used to prepare hardening filling mixtures. The ratio of binder to inert aggregate was 1:3, and the amount of water was selected for the sediment of the StroiTsNIL cone 10–12 cm [30].

To conduct research, a grinding department was built at the filling complex, a vibratory transport unit of a hardening filling mixture was mounted, a vibrating screen GV-1.2/3.3 (Ukraine) was developed, a DU-65 disintegrator-activator was mounted, a water activation section was installed with a unit for electrochemical cleaning of mine water (ECC). The results of these studies and pilot works are given below.

One of the main differences between the disintegration activation technology and grinding in a ball mill is that the speed of impact of slag particles on the working surfaces is an order of magnitude higher, and the particle acceleration is a million times faster than the free fall acceleration of the body [31].

The DU-65 disintegrator unit is mounted in the technological chain of the filling complex on the basis of the SB-75 automated concrete mixing plant (Ukraine) with a capacity of 70 m^3/h. For the first time in practice, the DU-65 disintegrator is used for industrial grinding of cement additives. The control circuit of the unit allows to change the modes of its operation. The working body of the disintegrator is 3 and 4-row rotors, the drive of which is carried out by electric motors with a capacity of 200 and 250 kW. The surfaces of the rotors are coated with a wear-resistant alloy. The specific net metal consumption of rotors is about 0.2 kg per 1 ton of granulated slag, which does not exceed 0.3 % in the cost of a hardening filling mixture. The technical feasibility and economic feasibility of using disintegrator technology for the preparation of slag additives is confirmed. The unit provides for the source material:

– productivity – 24 t/h;
– fraction yield – 0.074 mm – 50–55 %.

The energy consumption for 3-row rotors is 9 kWh/t, for 4-row rotors – 10–13 kWh/t. The replacement of rotors costs up to 15 % of the shift duration.

The disadvantage of disintegration technology is the decrease in the yield of the active fraction upon sticking of the working surfaces of the rotor with a change in the humidity of the initial slag. In real conditions, meteorological precipitation leads to disruption of the process continuity with a dry preparation scheme. A method of wet grinding in a disintegrator is known. This method consists in supplying water to the center of the disintegrator simultaneously with the material at a mass ratio of water to material (0.1–0.3):1, however, this method does not prevent wet material from sticking to the working surfaces of the rotors and does not increase the yield of the fine fraction. To eliminate this drawback, a wet grinding method has been developed, according to which, in addition to the simultaneous supply of water and material to the disintegrator in a mass ratio of 1:1, water is supplied before and after the material is supplied. This increases the yield of the active fraction in comparison with dry grinding by 10 % and reduces the dependence on weather conditions. Particles from slag, interacting with work surfaces, are crushed, and water flushes them from the surfaces of the disintegrator. The exclusion of slag sticking provides the impact force of the particle and its destruction. The scheme reduces the consumption of the original slag by 10–15 %, increases the bookmark's portability and is an element of integrated resource-saving technology.

6.2. Implementation results. Thus, the prospect of finding ways to improve laying works increases with an increase in the share of underground mining with the depletion of ore reserves available for open pit mining and the development of environmental trends of our time. Vibration transport increases the length of delivery of the hardening mixture, which allows to abandon the construction of new complexes in the development of peripheral areas of deposits. Improving the technology allows to draw into production stocks of man-made raw materials: tailings and inactive local materials after their preparation in the recommended apparatus activators [32].

A set of technical means is proposed for activating the components of hardening filling mixtures. In particular, binder (blast furnace granulated slag), inert aggregates, low-grade sands, dressing tailings, waste rocks and off-balance ores (by the content of useful components) ores (product of screening of substandard materials). As well as the activation of mixing water at the plants for electrochemical treatment (ECC) of mine water during manufacture and transportation to the place of their laying. A ball mill MB 3200×4500, a vertical vibratory mill MVV-0.7, a DU-65 disintegrator and a new set of vibrating feeders and screens of the type GV-1.2/3.2 are also proposed. They are introduced at such mining enterprises as [33]:

- State Enterprise «Eastern Mining and Processing Plant» and Balaklava Mining Administration (Ukraine);
- Joint-Stock Company «Tselinnyi Mining and Chemical Combine» (Republic of Kazakhstan);
- Public Joint-Stock Company Priargunsky Industrial Mining and Chemical Association named after E. P. Slavsky and Closed Joint-Stock Company Uralzoloto (Russian Federation) and other developed mining countries.

6.3. Promising areas for further research. An increase in the delivery range of hardening mixtures expands the scope of application of technologies with laying out the developed space, reduces capital and operating costs and eliminates the need to build new filling complexes with the diversion of significant areas of the earth's surface.

When hardening filling mixtures are delivered to man-made voids over long distances and at shallow depths of mining, the most promising is vibration gravity transport, which ensures homogenization of the mixture and strength increase due to their activation in the pipeline [34].

For the processing of industrial waste (tailings) it is required to create new technologies based on the latest achievements of science and technology using geotechnologies and disintegrators of the DU-65 type (Fig. 8).

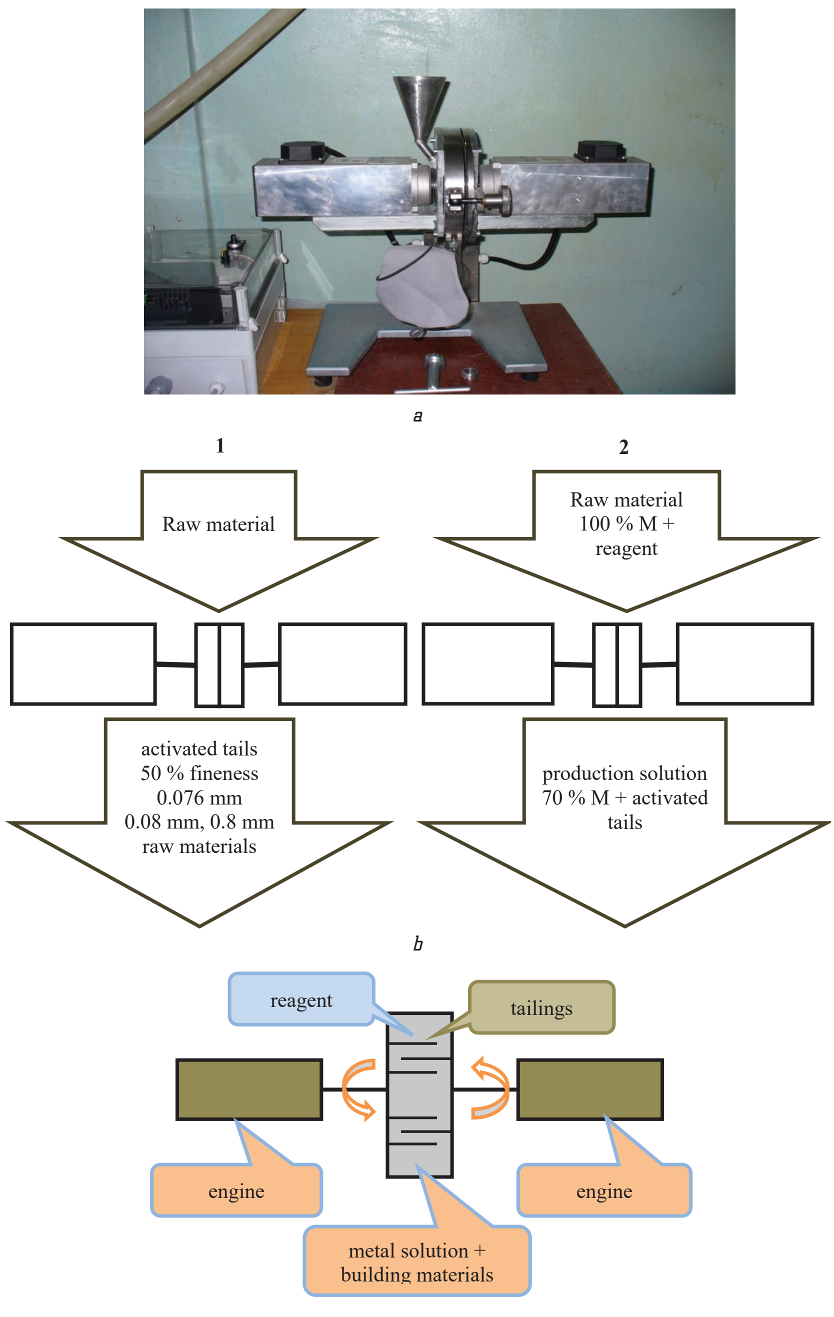

Fig. 8. Functions of the disintegrators: *a* – general view of the disintegrator type DU-11; *b*, *c* – schemes for the extraction of metals into solution from tailings of ore dressing using geotechnologies: 1 – for the preparation of concrete mixtures; 2 – for the extraction of metals and the preparation of concrete mixtures

It is necessary to conduct intensive research aimed at solving the problem of disposal of accumulated waste from mining and metallurgical production (MMP). Implementation of effective methods for the extraction of metals from such waste will improve the environmental situation in the areas of their storage and will provide an increase in the mineral resource base of the mining industry. The wide involvement of ore dressing tailings in the production of man-made reserves, as well as the processing of off-balance dumps, in terms of the content of useful components, of ores in modular plants, contribute to obtaining an additional source for industry in metals (Fig. 8). As well as reducing environmental pollution in developed mining countries of the world [35, 36].

7. SWOT analysis of research results

Strengths. Based on the justification of technologies and technical means for utilization of mining and metallurgical production wastes into an underground mined space, a complex of technical means is proposed for activating the components of hardening filling mixtures. Environmental and resource-saving technologies in the underground mining of mineral deposits with the laying of the developed space ensure the safety of operating facilities, safe mining, full use and protection of the subsoil and the environment, as well as the vital functions of the population living in the zone of influence of mountain objects [37, 38].

Weaknesses. The main negative impact of mining technology on the environment and humans is the high cost of preserving the daily surface and ensuring the livelihoods of the population living in the zone of influence of mountain objects, the withdrawal of large areas of land from use, etc. [39, 40]. Therefore, it is necessary to provide funds for the following activities:

– deep processing of industrial waste (tailings), which have a wide variety of mineral forms compared to 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 shrubs;
– continuous monitoring of environmental components in the zone of influence of mountain objects.

Opportunities. When delivering hardening filling mixtures to industrial voids over a long distance and a shallow depth of mining, the most promising is vibration gravity transport, which ensures homogenization of the mixture and increment of 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, of ores in modular plants, contribute to obtaining an additional source for industry in metals [41, 42].

Threats. To prevent dust transfer of contaminated material beyond mountain objects, it is advisable to plant sanitary protection zones and strips around them with tall tree species that will inhibit wind speed over these objects. These include mines, waste dumps and off-balance ores in terms of useful ore component, filling complexes, sites of preconcentration and heap leaching of metals from substandard ore raw materials, tailings, etc. In this case, dust will settle in these forest stands 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 to assess their impact on the environment and humans [11–13, 42].

8. Conclusions

1. It is established that the use of vibration, mechanical and electroactivation of the components of the hardening filling mixture in mining enterprises leads to an increase in the activity of substandard materials by up to 10–40 % for each device. In particular, the enrichment of inert materials at the GV-1.2/3.2 vibration screen (Ukraine) increases activity by 15–20 %.

2. It is proved that the activation of binders (blast furnace granulated slag) in the DU-65 disintegrator (Disintegrator, Estonia) increases the activity of the binder by 20–25 %, with the output of the active class of fractions with a particle size of 0.074 mm – by 55 % versus 40 % in ball mills.

3. Recommended vibration transport unit, which increase the activity of the solid components of the hardening filling mixture by 10–15 %. And electrodialysis devices for activating mixing water increase its activity by 30–40 %. The use of vibration gravity transport units ensures the filling of the filling mixture at a distance exceeding the height of the vertical stand by 15–20 times.

4. A set of technical means is proposed for activating the components of hardening filling mixtures (binder, inert aggregate and electrochemically purified mine mixing water) during manufacture and transportation to the place of their laying. This complex is introduced at the mining enterprises of State Enterprise «Eastern Mining and Processing Plant» and Balaklava Mining Administration (Ukraine), mines of Joint-stock company «Tselinnyi Mining and Chemical Combine» (Republic of Kazakhstan); Public Joint-Stock Company Priargunsky Industrial Mining and Chemical Association and Closed Joint-Stock Company Uralzoloto (Russian Federation) and other developed mining countries.

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