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INCREASING THE EFFICIENCY AND ENVIRONMENTAL SAFETY OF TECHNOLOGIES FOR EXTRACTING METALS FROM PROCESSING TAILINGS

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Abstract: *One of the most problematic areas of metal extraction from tailings of metal-containing mineral pro-cessing is the complexity of mineral mining and processing tailings utilization without extracting metals and sulfur compounds from them. This is hampered by insufficient efficiency of their secondary pro-cessing technologies. The study utilized the following data from literary sources and patent documentation in the field of technologies and technical means for metal extraction from tailings of metal-containing mineral processing; laboratory and production experiments; physical modeling of metal extraction from tailings of metal-containing mineral processing; data array processing using statistical and probability theory methods, as well as mathematical modeling. The paper presents the main scientific and practical results of research and development of new technologies and technical means for metal extraction from ore processing tailings. Mechanochemical processes during ore enrichment tail-ings utilization into man-made voids and activation of useful ingredient extraction processes are de-scribed. It is shown that mechanic-chemical activation of enrichment tailings in a disintegrator increases metal extraction into solution by 10–25% during one processing cycle by two orders of magnitude faster than agitation leaching and can increase extraction during multiple processing. The use of activation of hardening backfill mixture components at mining enterprises leads to an increase in their activity for each apparatus by up to 10–40%. The conducted studies are a step towards creating a highly efficient technology for ore enrichment tailings utilization with the production of metals and hardening mixture components. The main advantages of the technology are the possibility of utilizing enrichment waste with a storage time of more than 10 years and obtaining metals in an amount of 20 to 60% of their content in the tailings. Mechanochemical activation during a single treatment increases metal ex-traction into solution by up to 25% compared to the base value and has a reserve for increase with an increase in processing cycles. Activation in a disintegrator without leaching increases the strength of the hardening mixture with the addition of cement from 1.30 to 1.52 MPa or by 17%. The mechanochemical technology is recommended for implementation at enterprises of the mining industries. The phenomenon of activation during processing in a disintegrator has been confirmed in related industries. The results of the research can be used in the extraction of metals from tailings of metal-containing minerals at mining and processing enterprises of Ukraine, the Republic of Kazakhstan, the Republic of Kyrgyzstan and other developed mining countries of the world.*

Keywords: *tailings, metal extraction, mechanochemical processes, utilization, activation, efficiency, environmental safety*

1. Introduction

Problem statement. The technology of mining and processing metal-containing minerals is characterized by causing multifaceted damage to the environment [1], [2]. Mineral mining and processing tailings are often disposed of without extracting metals and sulfur compounds from them, which is hampered

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by the insufficient efficiency of secondary processing technologies. Synergistic processes occur in the tailings, the products of which affect the ecosystems of the environment [3], [4]. Known heap leaching technologies are characterized by a lengthy process. Activation of tailings allows accelerating the extraction of metals and reducing the migration time of harmful elements into ecosystems [5], [6]. Therefore, the strategy for further development of ore raw material mining requires the introduction of fundamentally new technologies that will ensure the protection and rational use of the subsoil, increasing the economic efficiency and environmental safety of ore mining and processing, as well as the sustainable development of mining regions - an important scientific and practical task that requires a prompt solution [7], [8].

This work is a continuation of the research, the main scientific and practical results of which were obtained in the course of research projects (scientific supervisor V.I. Lyashenko): "Research and development of dust suppression methods during transportation, storage, warehousing of minerals and waste from ore mining and processing at uranium industry enterprises" ("Dust suppression"). State registration number 0102U003095; "Research and development of technology and formulation of hardening mixtures from tailings of GMZ-2 for backfilling of surface storage maps", State registration number 0108U008936 and are most fully presented in works with the participation of the authors [9]. In the course of research, the phenomenon of natural bischofite, leaching of metals from poor, off-balance and substandard ores, processing tailings, as well as vibration machines and mechanisms in mining production were taken into account and used [10].

2. Analysis of the latest research and publications

A number of research, design and engineering institutes and universities of Ukraine are engaged in the development, testing and implementation of effective technologies in production. In particular, such research in Ukraine is carried out by the following institutions: M. S. Polyakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM NAS of Ukraine, Dnipro): works by A. F. Bulat, O. M. Zorin, V. V. Vinogradov, T. A. Palamarchuk; Scientific Research Mining Institute of Kryvyi Rih National University (NIGRI KNU, Kryvyi Rih): works by A. G. Katkov, I. S. Zitzer, V. S. Nigmatulin, V. P. Voloschenko, V. V. Tsarikovsky, G. K. Khizhnyak, A. P. Grigoriev, V. D. Zaporozhets, V. I. Nikonets; National Technical University "Dnipro Polytechnic", Dnipro: works by M. M. Protodyakonov, A. M. Dinnik, A. V. Savostyanov, S. G. Borisenko, A. I. Zilberman, A. V. Kolokolov, V. I. Bondarenko, P. I. Ponomarenko, G. A. Simanovich, L. M. Shirin, V. I. Buzilo, I. A. Kovalevskaya, V. Ya. Kirichenko, Yu. M. Khomenko; Krivoy Rog National University, Krivoy Rog: works by G. M. Malakhov, V. A. Shchelkanov, Yu. P. Kaplenko, V. F. Lavrinenko, B. N. Andreev, E. I. Logachev; State Enterprise "Ukrainian Research and Design and Exploration Institute of Industrial Technology" (SE "UkrNIPRI Industrial Technology, Zhovti Vody): works by A.K. Avdeev, V.M. Melnichenko, Yu.I. Koshik, M.M. Sleptsov, Yu.Ya. Savelyev, V.I. Lyashenka and others [11], [12].

Despite the positive experience of industrial leaching so far only of uranium, copper, gold, insufficient study of the process prevents the widespread introduction of the method in deposits of ores of other metals. Underground leaching in production blocks without taking into account all natural and man-made factors can discredit the idea itself. Therefore, the main task of developing the method is to develop the scientific basis for the new technology [13]. In the Krivoy Rog iron ore basin (Ukraine), over 6 billion tons of iron ore raw materials have been mined, which has completely led to the irreversible transformation of the environment from a natural to a man-made ecosystem. About 13 billion tons of rocks have accumulated in the dumps, which together with the tailings occupy an area of more than 63 thousand hectares, another 60 thousand hectares are in the flood zone. Significant volumes of potentially dangerous voids have formed in the subsoil, the sudden collapse of which threatens to disrupt the earth's surface with failures and shear zones. Further development of deposits leads to an increase in the depth of mining operations, an increase in the burden on the environment and the health of the population living in the zone of their influence.

Near iron ore deposits, in addition to the well-known factors, there is a threat to active agricultural activity. The zone of impact of mining enterprises on natural landscapes with a radius of 15-20 km is characterized by a high level of pollution with fine mineral particles (500-1000 kg/ha per year), chemicalization of soils (pH – 7.5-8.5) and accumulation of aggressive metals in the soil [14], [15]. Beneficiation tailings of ferruginous quartzites contain metals that are not extracted by processing, which are transformed into a mobile state and affect the ecosystems of the environment.

The use of beneficiation tailings as a raw material becomes possible with an increase in their activity at the time of formation of new mineral surfaces using a special energy state. Particular criteria for the efficiency of beneficiation processes are the degree of disclosure of mineral units, extraction of metals, time

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and cost of processing [16], [17]. Enrichment methods that combine magnetic, gravitational and electrochemical separation and enrichment techniques allow in some cases to extract metals from tailings, but not completely and not all, because one energy is predominantly used - mechanical energy. Hydrometallurgical and chemical enrichment methods using the leaching phenomenon differ in the duration of extraction. The method of leaching metals in the working element of the disintegrator is fundamentally different in that a special type of energy is accumulated in the disintegrator. In addition to an increase in the temperature of the substance, its structural state changes under the influence of overloads. A full-factor experiment is a tool for proving the effectiveness of the methods. During the experimental extraction of metals by leaching, the metal extraction rates are compared for reagent leaching options [18].

3. Statement of the problem and its solution

The most relevant direction is the use of mineral enrichment tailings in the composition of the hardening mixture not only as inert fillers, but also as binders. Small fractions of enrichment up to 0.076 mm in size, including carbonate components, are used as binders. Grinding the enrichment tailings to a fine fraction allows the production of filling mixtures of sufficient strength to fill the main volume of technogenic voids. Physicochemical processes in solids proceed faster and more completely, the larger the surface of the substance participating in the process. The efficiency of the technology of mechanochemical activation of ferruginous quartzite beneficiation tailings is assessed by comparing its performance with that of agitation leaching in percolators according to the metal extraction criterion using the Vencken-Box method, with the results interpreted in the form of logarithmic or polynomial interpolation. Reduction of cement consumption for the preparation of hardening mixtures while ensuring the standard strength of backfill massifs, expansion of the area of utilization of beneficiation tailings and improvement of the state of the environment are ensured by the implementation of several directions.

In [7], it is proposed to include in the composition of the backfill mixture:

− additionally ground blast-furnace acid slag as a binder, and a mixture of ferruginous quartzite beneficiation tailings with slag crushed stone as a filler;

− ground by-product of vanadium production, and beneficiation tailings as a filler;

− ground acid granulated blast furnace slag, and as a filler - waste from the enrichment of wet magnetic separation of ferruginous quartzites, a by-product of vanadium production and a superplasticizer.

In [1], [14] it is recommended to use enrichment tailings and Portland cement crushed in a disintegrator as a filler. The composition of the backfill mixture in [12] includes steelmaking slag and an activator - burnt rocks of the mine dump and sludge from the neutralization of electrolytes with lime. In [3], [6] it is proposed to use waste from the leaching of enrichment tailings, quicklime or sodium sulfonate for backfilling the mined-out space. The main negative impact of mining technology on the environment and humans is the high costs of supporting the livelihoods of the population living in the area of influence of mining facilities, alienation of large areas of land, especially highly fertile ones, from use, etc. The areas considered involve using enrichment tailings mainly as a filler without extracting useful and valuable metals from them, reducing the completeness of subsoil use.

Research object - technologies and technical means for extracting metals from tailings of metal-containing mineral processing. One of the most problematic areas is the difficulty of utilizing tailings from mining and processing minerals without extracting metals and sulfur compounds from them, which is hampered by the insufficient efficiency of secondary processing technologies [7], [8].

Research objective - improving the efficiency and environmental safety of technologies for extracting metals from tailings of ore raw material processing based on mechanochemical processes during their disposal in man-made voids and activation of processes for extracting useful ingredients. This will ensure the protection and rational use of subsoil, increasing the economic efficiency and environmental safety of ore mining and processing. To achieve the goal set in the work, the authors outlined and solved the following research tasks:

1. To substantiate the environmental feasibility of using nature-protecting technologies for processing metal-containing tailings.
2. To develop mathematical models taking into account the environmental requirements of the products of processing metal-containing tailings.
3. To determine the quantitative characteristics of the effect of nature and resource conservation taking into account the processing of metal-containing tailings.

The possibility of using beneficiation tailings as raw materials for the manufacture of hardening mixtures is proven in the course of research. A sample of beneficiation tailings of ferruginous quartzites was processed in a DESI-11 disintegrator from Gefest, Tallinn, Estonia (Fig. 1).

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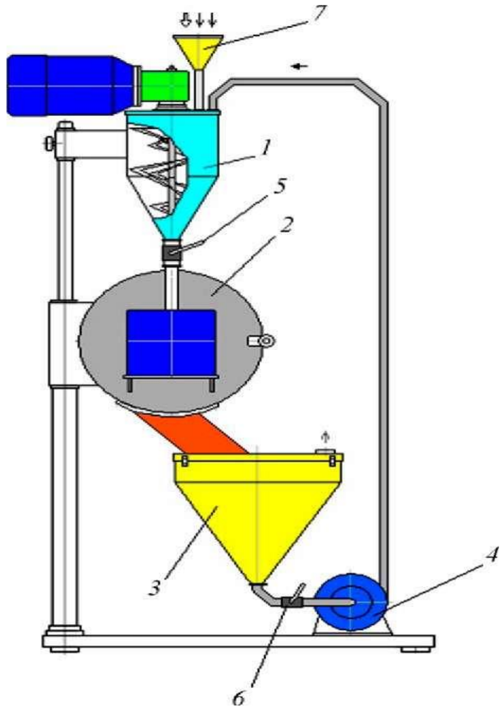

Fig. 1. Schematic diagram of the laboratory disintegrator DESI-11 for activation and leaching of minerals: 1 – mixer; 2 – disintegrator; 3 – receiving bin; 4 – pump; 5, 6 – tap; 7 – funnel

Characteristics of the disintegrator: maximum productivity is ensured when processing material with a density of 2...3 g / cm^3, rotor speed of 12,000 per minute, initial particle size of 2.5 mm, and humidity of the crushed material of 2%. The efficiency of the technologies was studied by comparing leaching options in a percolator and a disintegrator. Factors influencing the extraction of metals into the production solution (such as the content of the reagent in the leaching solution), the rotation frequency of the disintegrator rotors; the number of processing cycles in the disintegrator and the liquid-to-solid ratio (L:S) were varied at three levels - minimum, zero and maximum. Activation of the mixture components on a vibrating screen, in a disintegrator and a vibration pipeline with water activation by settling salts and impurities expands the limits of using progressive technologies with backfilling with hardening mixtures [19].

The quenching with a hardening backfill mixture of various compositions and strengths ensures the best performance in subsoil use and environmental protection (Fig. 2).

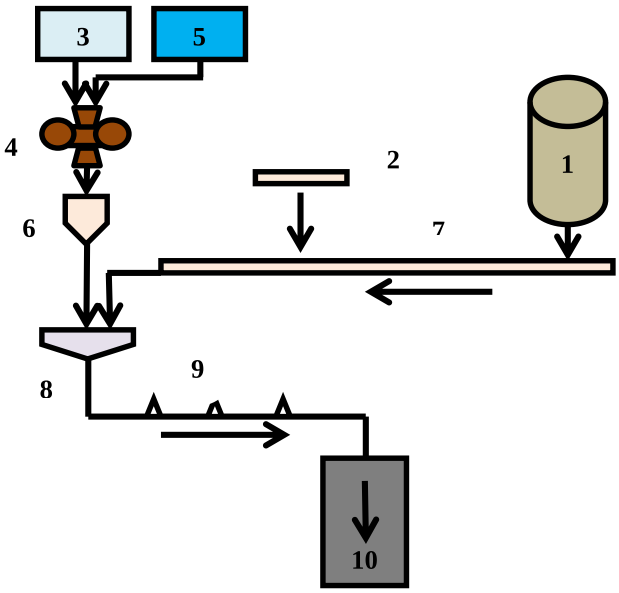

Fig. 2. Scheme of activation of components of hardening mixtures during their production and transportation: 1 − cement bin; 2 − vibrating screen of inert fillers; 3 − blast furnace slag; 4 − disintegrator-activator DU-65 (company "Dezintegrator", Estonia); 5 − activated mixing water; 6 − vertical vibrating mill MVV-0.7 (Ukraine); 7 − conveyor; 8 − mixer; 9 − vibrators; 10 − block chamber

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Mineral waste is processed using various methods - electrochemical, ultrasonic, thermal, mechanochemical, hydrochemical, etc. The division into stages of mineral reactivity indicators, proposed by the authors, depending on the energy costs required to carry out the mechanical activation of various minerals, is presented in Table 1.

Table 1. Stages of mechanical activation of minerals

Stage	Surface, m^2/g	Defects, changes and amorphization	Processes with activation effect	Ore types and energy consumption (N), kW • h/t
1	1–2	Electronic and atomic defects, dislocations (linear extended defects) of all types	Flotation, magnetic separation, methods based on the surface properties of the mineral	Quartz-feldspar, cassiterite, phosphate, spodumene, scheelite, magnetite (N < 10)
2	10–15	Reducing particle size and enhancing microdistortions	Chemical and thermochemical enrichment, bacterial and autoclave leaching	Sulfates, sulfides, bauxites, phosphates, kaolinite, scheelite, wolframite, chromite, titanium-magnetite, rare earth ores (N < 500)
3	Over 15	Propagation of micro-distortions and transition to an X-ray amorphous state	Opening and phase transformations before hydrometallurgical processes	Spodumene, lepidolite, pyrochlore, cassiterite and other concentrates (N > 1000)

In order to determine the possibility of using ore beneficiation tailings as construction raw materials, the effect of weakening the bearing properties of products due to natural leaching of metals was studied. The approximate ratio of components in the studied beneficiation tailings was established, in % on average: coarse-grained granites - 40%; porphyrites - 30%; sandstones - 20%; gangue material - 8%; ore minerals - 2%, pyrite - 1.4%; sphalerite - 0.6%; galena - 0.06%; chalcopyrite – 0.05% [5].

4. Research results

Theory of the issue. The degree of metal extraction was studied by comparing the leaching options in a percolator and in a disintegrator for 60 min. Based on the results of the experiments, it was established how the activation of the enrichment tailings increases the extraction of metals from the tailings. The results of the experiments were interpreted in the form of logarithmic or polynomial interpolation. The process of opening the flotation enrichment tailings by activation in a disintegrator was described mathematically. The regression analysis of the experimental data is given in Table 2.

Table 2. Regression analysis of experimental data

Regression equation	Indicators and criteria of significance
1. Disclosure of flotation tailings by activation in a disintegrator $\varepsilon_1 = 2.095 + 1.231X_1 + 0.444X_2 + 0.275X_3 + 0.176X_4 + 0.290X_1^2 + 0.330X_2^2 - 0.325X_3^2 + 0.225X_4^2 - 0.127X_1X_2 + 0.047X_2X_3 + 0.036X_3X_4$	$R^2 = 0.977$; $S_{ad} = 0.0673$; $F = 225.99$
2. Agitation leaching of tailings activated in a disintegrator in a dry state $\varepsilon_2 = 2.447 + 1.736X_1 + 0.714X_2 + 0.48X_3 + 0.372X_4 + 0.655X_1^2 + 0.705X_2^2 - 0.27X_3^2 + 0.142X_1X_3 + 0.147X_1X_4 + 0.136X_2X_3 + 0.198X_2X_4 + 0.184X_3X_4$	$R^2 = 0.954$; $S_{ad} = 0.3393$; $F = 75.47$
3. Leaching of tailings in a disintegrator $\varepsilon_3 = 3.091 + 2.381X_1 + 1.015X_2 + 0.698X_3 + 0.583X_4 + 1.034X_1^2 + 1.104X_2^2 - 0.276X_3^2 - 0.176X_4^2 + 0.259X_1X_3 - 0.268X_1X_4 + 0.255X_2X_3 + 0.339X_2X_4 + 0.315X_3X_4$	$R^2 = 0.9384$; $S_{ad} = 1.0111$; $F = 43.03$

Note: $X_1 = 2 \div 10$ g/l – sulfuric acid content in the leach solution; $X_2 = 20 \div 160$ g/l – sodium chloride content in the leach solution; X_3 – weight mass ratio ($4 \div 10$) leach solution and leachable mass (50 g) in a single experiment; $X_4 = 0.15 \div 1{,}00$ h – leaching time (t); ε_1 ε_2 ε_3– random error for the corresponding regression equations; R^2 – coefficient of determination; S_{ad} – accuracy of determining the estimates of regression coefficients; F – coefficient of determination)

Based on the analysis of the regression dependence, a graph of the change in metal extraction from the reagent content was constructed. The factors "ratio L:S" and "rotation speed of the disintegrator rotors" are set at zero. The regression analysis algorithm is presented as a computer program in the MATLAB language with a determination coefficient for the dependence of iron extraction $R^2 = 0.94$.

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To analyze the parameters of mineral activation, graphs were constructed showing the dependence of metal extraction on each of the predictors. The accepted designations are: row 1 – extraction of zinc into the production solution; row 2 – extraction of lead into the production solution; row 3 – extraction of iron into the production solution (Fig. 3–6).

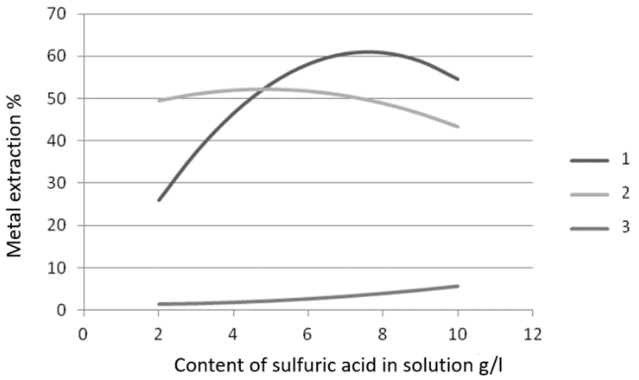

Fig. 3. Dependence of metal extraction on the concentration of sulfuric acid

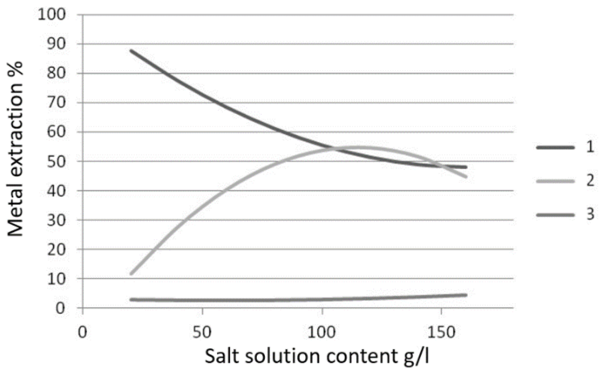

Fig. 4. Dependence of metal extraction on salt concentration

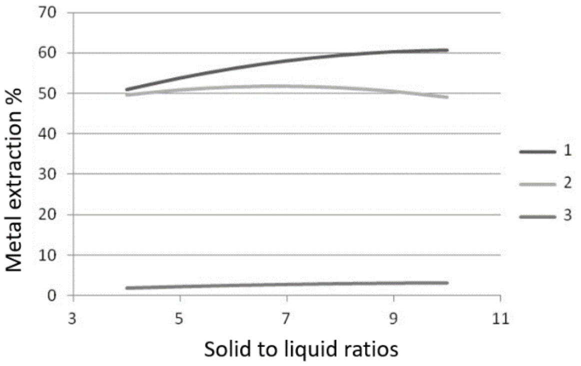

Fig. 5. Dependence of metal extraction on the ratio of solid and liquid phases

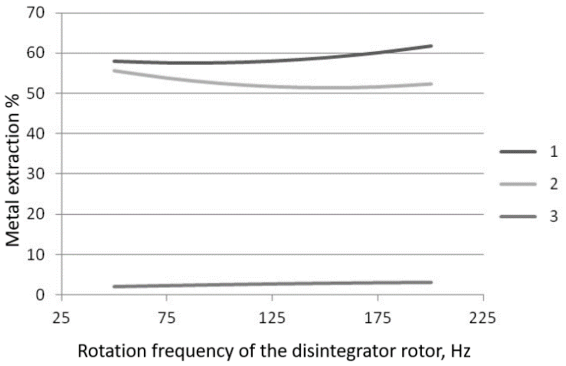

Fig. 6. Dependence of metal extraction on rotor speed

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The criterion for evaluating the variants is the value of metal extraction established on the basis of processing samples taken every hour of the plant operation and upon completion of leaching. The variable factors controlled during the experimentation were: reagent content, liquid to solid phase ratio, leaching time, disintegrator rotor speed, and number of processing cycles. The leaching parameters included: yield of active class 0.08, chemical composition of the ores under study, metal content in solution, mg/l, metal extraction into solution, % [20].

Variable factors in the experiments:

− sulfuric acid and sodium chloride content, X1, X2 at levels: X1-1 … 2, 0 … 6 and 1 … 10 g/l, X2 -1 … 20.. 90 and 1 … 160 g/l;

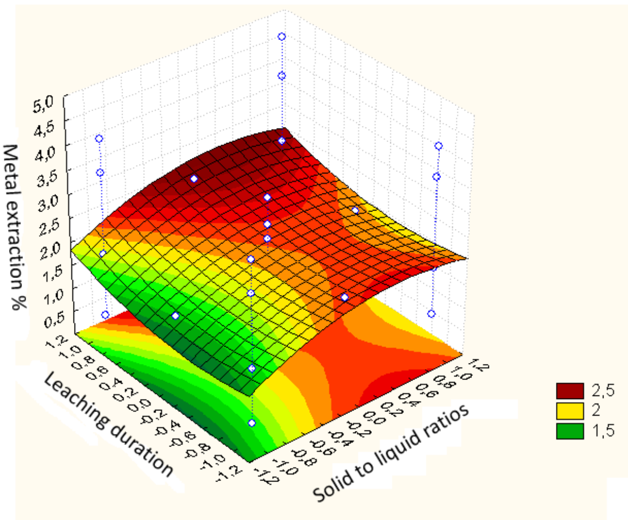
− L:S ratio, X3 at levels: X3 – 1 … 4, 0 … 7 and 1 … 10;

− duration of agitation leaching, X4 at levels: X4 -1 … 0.25, 0 … 0.5, 1-1 hour, except for experiments of the 3rd and 5th stages;

− rotation speed of the disintegrator rotors, X5 at levels: X5 -1 … 50, 0 … 125, 1 … 200 Hz, except for experiments of the 1st stage;

− number of leaching cycles X6, by levels: X6 -1 …3, 0 …5, 1 …7, for experiments of the 5th stage.

The amount of tailings subjected to leaching in a single experiment of the first, third, fourth and fifth stages was 50 g. At the second stage, the amount was increased taking into account the removal of small fractions with dust. Based on the analysis of the regression dependence, a graph of the change in metal extraction from the reagent content was constructed (Fig. 7).



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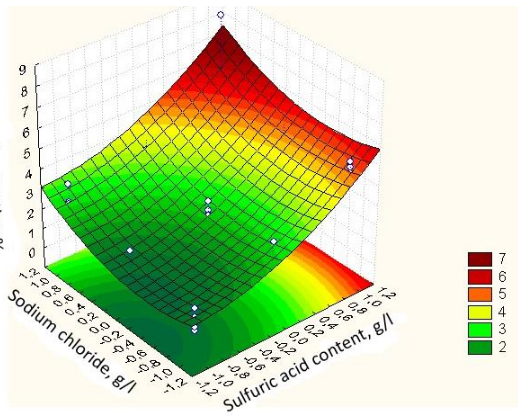

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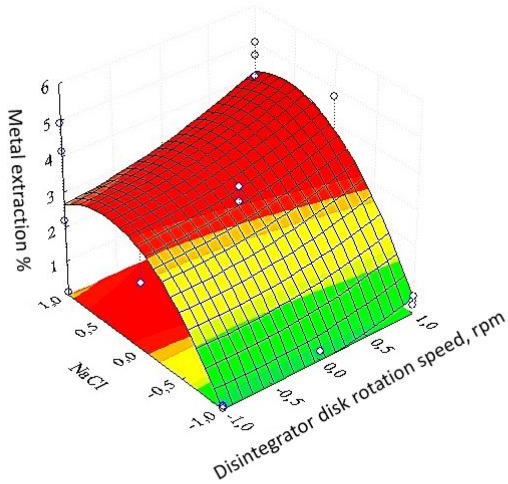

c

Fig. 7. Dependences of metal extraction on: a – leaching duration and "L:S ratio" at zero level of disintegrator disk rotation speed factors, sulfuric acid and salt content; b – sodium chloride and sulfuric acid content; c – sodium chloride content, g/l and disintegrator disk rotation speed, rpm.

5. Research results

Given the low content of associated metals, their concentration in solutions is increased by evaporation of solutions or precipitation of a complex gel from solutions with soda, converting metals into an insoluble form. Traditional enrichment technologies operate with processes with a low energy level without changing the phase state, so they can only be used at the initial stage of deep processing to separate tailings into commercial and substandard mineral mass [21].

5.1. Examples of using disintegrator technology

Ferruginous quartzites. Tailings from the enrichment of ferruginous quartzites from the iron ore deposits of the Krivoy Rog basin (Ukraine) are finely dispersed mineral powder with a fraction content of less than 0.071 mm in size of 40-70%. Chemical composition of the tailings: SiO_2 – 64%, Fe – 8%, Al_2O_3 – 5,2%, Mn – 3,2%, K_2O – 0,7%, P – 0,1%, Ca – 0,8%, MgO – 0,2%, Cu – $5\cdot10^{-3}$%, Ni - $4\cdot10^{-3}$%, Zn - $5\cdot10^{-4}$%, As, Ba, Be, Bi, Co, Cr, Li, Mo, Nb, Pb, Sb, Sn, Sr, Ti, V, Y – at the level $(30\text{-}50)\cdot10^{-5}$%.

With an initial iron content of 8% in the sample under study, approximately 1% of the iron is extracted by single leaching, and after three passes of the tailings through a disintegrator into a solution of 3% iron. By further increasing the number of processing cycles, it is possible to achieve a level of iron content that is safe according to sanitary requirements [22].

The chemical composition of the initial sample of tailings is characterized by the content As, Ba, Be, Bi, Co, Cr, Li, Mo, Nb, Pb, Sb, Sn, Sr, Ti, V, Y – at the level $(30\text{-}50)\cdot10^{-6}$%. After mechanochemical processing, the content in secondary tailings does not exceed the values permissible for building materials. Mechanochemical activation during single processing increases the extraction of metals into the solution compared to the base value by up to 25% and has a reserve for increase with an increase in processing cycles. Processing for the same time is characterized by the indicators given in Table 3.

Table 3. Results of metal leaching

Type of leaching	Residue in tails, %					
	Al_2O_3	Mn	K_2O	P	Ca	MgO
Agitation leaching	4.9	2.8	0.3	0.07	0.25	0.16
Activated tailings leaching	4.2	2.5	0.2	0.07	0.23	0.14
Disintegrator leaching	3.7	2.3	0.2	0.06	0.20	0.11
Mechanochemical activation	3.5	2.2	0.2	0.07	0.18	0.11

Maximum extraction is achieved with mechanochemical activation of tailings and depends on the duration of the processes. By increasing the duration of the process, it is possible to extract target components to the background content. After the extraction of metals to the level of sanitary requirements, the enrichment waste is suitable for the manufacture of stowage mixtures and concrete commercial products, providing the required grade with a minimum consumption of cement binder. The authors confirmed the feasibility of mechanochemical activation of metal-containing raw materials with the supply of a leaching reagent to the working element of the disintegrator. Thus, the method of extracting metals from enrichment tailings, which involves combining the processes of chemical enrichment and activation in the disintegrator, can be regarded as promising. Strengthening the mechanochemical effects allows increasing the efficiency of metal leaching processes in the disintegrator (Table 4).

Table 4. Directions for improving metal leaching

Impact	Purpose of improvement	Implementation method
Mechanical	Increase of reaction surface	Increasing impact pulses
Chemical	Acceleration of chemical processes	Preliminary treatment with acid solution
Combined	Comprehensive improvement of indicators	Treatment with acid solution with simultaneous mechanical activation

One of the disadvantages of the known methods is the decrease in the chemical activity of the leaching reagent and the efficiency of extracting useful components due to the adhesion of the grains of the processed material. Activation in a disintegrator without leaching increases the strength of the mixture with the addition of cement from 1.30 to 1.52 MPa or by 17%. Mixtures activated in a disintegrator without adding cement can be used to fill the overwhelming volume of stopes. Technologies with activation and leaching in a disintegrator exploit the phenomenon of weakening the intra- and intermolecular bonds of an elementary mineral particle and can be used to intensify the processes of leaching metals.

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Maximum extraction of metals is ensured by a combined mechanochemical effect on the mineral in a disintegrator with the generation of instantaneous physicochemical processes and with a change in the phase state of the metal. Combining the processes of mechanical activation and chemical leaching allows metals to be extracted 2 orders of magnitude faster than with agitation leaching, which ensures the economic efficiency of the technology. Leaching in disintegrators is used to increase the activity of mixture components during the preparation of hardening mixtures (Fig. 8).

Activated beneficiation tailings are used in the composition of the hardening mixture as inert fillers and as binders, providing strength of 0.5 - 1.5 MPa, sufficient for backfilling most of the mined-out space. Thus, the creation and implementation of new technologies and technical means for extracting metals from tailings of iron-containing ores processing forms an ecological and economic effect from the cost of commercial products and a decrease in damage to the environment. Technologies with ore leaching allow increasing extraction while reducing the duration of leaching. The developed technology is recommended for development at enterprises of the mining industries, taking into account the prospects for the transition to underground mining, for example, at the Krivbass deposits (Ukraine). The feasibility of involving ore processing waste in economic circulation with profit due to the production of additional commercial products requires continued research on the topic of extracting metals from mined ores due to the phenomenon of mechanochemical impact [23].

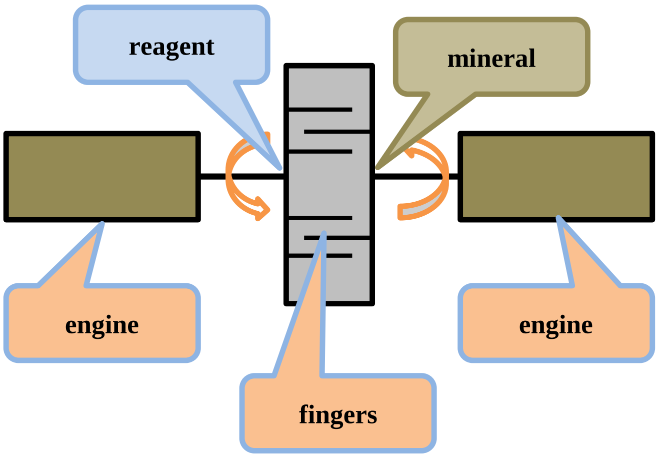

Fig. 8. Scheme of leaching in a disintegrator

5.2. Further research

Modernization of the existing technology and technical means should be carried out by increasing the time of combined activation in the disintegrator and solving the problem of feeding the primary reagent solution and recirculating the production solution in the working chamber. The main condition for the safety of mining production is the minimization of the volumes of minerals released to the surface and the utilization of substandard raw materials already released to the surface.

The greening of mining production is still developing through the management of the process of formation of technogenic deposits during the development of deposits and the transfer of inactive reserves of technogenic deposits into active ones by influencing them with physical and chemical processes. Reserves of technogenic deposits cannot be eliminated by existing processing technologies.

The main direction of further research is the optimization of development methods, technological processes of extraction and processing according to the criterion of minimizing production waste. Extraction of metals from man-made deposits can be implemented by alternative technologies – combined technologies of leaching metals from ores [24].

In our opinion, the following are new scientific and methodological provisions:

– it has been established that activation of enrichment tailings increases metal extraction, which is described as a logarithmic or polynomial dependence;

– based on the analysis of the regression dependence, a graph of the change in metal extraction from the reagent content has been constructed, while the factors “L:S ratio” and “disintegrator rotor speed” are set at zero;

– it has been shown that extraction is achieved with mechanochemical activation of tailings and depends on the duration of technological processes, while increasing the duration of the process, it is possible to extract target components to the background content.

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6. Conclusions

It is noted that mechanochemical activation of enrichment tailings in a disintegrator increases metal extraction into solution by 10–25% during one processing cycle by two orders of magnitude faster than agitation leaching and can increase extraction during multiple processing. The use of activation of components of the hardening backfill mixture at mining enterprises leads to an increase in their activity for each device by up to 10–40%. The completed studies are a step towards creating a highly efficient technology for ore enrichment tailings utilization with the production of metals and components of hardening mixtures, the main advantages of which are the possibility of utilizing enrichment waste with a storage time of more than 10 years and obtaining metals in an amount of 20 to 60% of their content in the tailings.

Mechanochemical activation during a single treatment increases metal extraction into solution by up to 25% compared to the base value and has a reserve for increase with an increase in processing cycles. Activation in a disintegrator without leaching increases the strength of the hardening mixture with the addition of cement from 1.30 to 1.52 MPa or by 17%. The phenomenon of activation during processing in a disintegrator has been confirmed in related industries.

For the processing of man-made waste (tailings and other metal-containing minerals), which have a greater variety of mineral forms compared to conventional ores, it is necessary to develop new technologies based on the latest achievements of science and technology.

It is necessary to intensify research aimed at solving the problem of recycling accumulated waste of the mining and metallurgical complex. The implementation of effective methods for extracting metals from such waste will improve the environmental situation in the areas of their storage and ensure an increase in the mineral resource base of the domestic industry. Therefore, the authors propose to consider the issue of the advisability of carrying out the following measures [25]:
- wide involvement in the production of man-made reserves of ore enrichment tailings, as well as the processing of off-balance (in terms of the content of useful components) ore dumps in modular units;
- reclamation of the territory of industrial sites and the territory adjacent to them after the end of the exploitation of mineral deposits;
- landscaping of the reclaimed territory with grass and shrub vegetation;
- constant monitoring of environmental components in the zone of influence of mining facilities and other measures.

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References

[1] **Golik V.I., Stradanchenko S.G., Maslennikov S.A.**, 2015
Experimental Study of Non-Waste Recycling Tailings Ferruginous Quartzite. International Journal of Applied Engineering Research, No. 10 (15), pp. 35410-35416.

[2] **Haifeng W., Yaqun H., Chenlong D., et al.**, 2012
Development of Mineral Processing Engineering Education in China University of Mining and Technology. Advances in Computer Science and Engineering, AISC 141, Springer-Verlag, Berlin, Heidelberg. pp. 77-83.

[3] **Burdzieva O.G., Zaalishvili V.B., Beriev et al.,** 2016
Mining Impact on Environment on the North Ossetian Territory. International Journal of GEOMATE, No. 10 (1), pp. 1693-1697.

[4] **Gurin A.A., Shapovalov V.A.**, 2022
Assessment of Technologies and Technical Features for the Recovery of the Phenomenon of Natural Bichofite in Galusia Ecology and Mining Industry. Bulletin of the Krivorizky National University, zb. Sci. – Krivy Rig. - VIP. 55. – pp. 76–82, (in Ukrainian), Doi: 10.31721/2306-5451-2022-1-55-76-82.

[5] **Gavrishev S.E., Kornilov S.N., Pytalev I.A., Gaponova I.V.,** 2017
Improving the Economic Efficiency of Mining Enterprises by Bringing Technogenic Geo-Resources into Operation. Mining Journal, No. 12. pp. 46-51 (in Russian).

[6] **Osipov Yu.V., Koshelev A.E., Voznesensky A.S.,** 2020
Experimental Studies of Deformation Properties of Bischofite. Ferrous Metallurgy. Mining Information and Analytical Bulletin, No. 10, pp. 5-15, (in Russian), DOI: 10.25018/0236-1493-2020-10-0-5-15.

[7] **Glebov A.,** 2011
Selection of Gathering Autotransport for the Systems of Cyclical-and-Continuous Technology. Mining of Mineral Deposits, 11(4), pp. 11-18, (in Ukrainian), https://doi.org/10.15407/mining11.04.011.

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pp. 77-87

[8] **Lyashenko V.I., Golik V.I., Dyatchin V.Z.,** 2020
Increasing Environmental Safety by Reducing Technogenic Load in Mining Regions. Izvestiya, Ferrous Metallurgy, 63 (7):529-538, (in Russian), https://doi.org/10.17073/0368-0797-2020-7-529-538

[9] **Gurin A.A., Shapovalov V.A.**, **Lyashenko V.I.,** 2024
Evaluation of Technologies and Technical Means for Using the Phenomenon of Natural Bischofite in the Field of Mining Industry and Ecology. Mining Revue, vol. 30, No. 3, pp. 30-42, https://doi.org/ 10.2478/minrv-2024-0024.

[10] **Lyashenko V.I., Shapovalov V.A., Dyatchin V.S., Uchytel S.O.,** 2024
Theory and Practice of Developments in the Field of Separation and Extraction of Metals at Mining and Metallurgical Enterprises, Mining Revue, vol. 30, No. 3, pp. 71-85, https://doi.org/ 10.2478/minrv-2024-0028.

[11] **Golik V.I., Dmitrak Yu.V., Razorenov Yu.I., Maslennikov S.A., Lyashenko V.I.,** 2021
Mechanochemical Technology of Iron Extraction from Enrichment Tailings. Izvestiya. Ferrous Metallurgy, vol. 64, no. 4, pp. 282-291, (in Russian), https://doi.org/10.17073/0368-0797-2021-4-282-291.

[12] **Khasheva Z.M., Golik V.I.,** 2015
The Ways of Recovery in the Economy of the Depressed Mining Enterprises of the Russian Kaisas. International Business Management, No. 9(6), pp. 1210-1216, (in Russian).

[13] **Valiev N.G., Propp V.D., Vandyshev A.M.,** 2020
The Mining Department of UGSU is 100 years old. News of Higher Educational Institutions. Mining journal, No. 8, pp. 130-143, (in Russian).

[14] **Dushin A.V., Valiev N.G., Lagunova, Y.A., et al.,** 2018
Ural Mining and Moscow Mountain. The Collaboration of Universities Gorn, No. 4, pp. 4-10, (in Russian)

[15] **Klyuev V.R., Bosikov I.I., Mayer A.V., Gavrila O.A.,** 2020
Comprehensive Analysis of the Use of Efficient Technology to Improve the Sustainable Development of Natural-Technical Systems. Sustainable Development of Mountain Territories, No. 2, pp. 283-290, (in Russian).

[16] **Hint Y.A.,** 1981
UDA-Technology: Problems and Prospects, Tallin, Valgus, 36 p. (in Estonian).

[17] **Kongar-Suryun Ch.B., Faradzhov V.V., Tyulyaeva Yu.S., et al.,** 2021
Investigation of the Effect of Activation Treatment on Halite Processing Waste during the Preparation of the Filling Mixture. Mining Information and Analytical Bulletin, No. 1, pp. 43-57. (in Russian).

[18] **Eremeeva J.V., Sharipzhanov G. H., Nitkin N.M., et al.,** 2016
Influence of Technological Factors in the Mix and Nature of Nanoscale Particles on the Mechanical Properties of Powder Alloy Steel. Nanotechnology: Science and Production, No. 3, pp. 57-76.

[19] **Lyashenko V.I., Golik V.I.,** 2017
Scientific, Design and Technological Support for the Development of Uranium Production. Achievements and Tasks. Mining Information and Analytical Bulletin, No 7, S.137–152, (in Russian).

[20] **Lyashenko V.I.,** 2017
Development of Methodological Foundations for Research and Assessment of the Ecological and Economic Efficiency of Environmental Technologies and Technical Means in the Extraction and Processing of Ore Raw Materials. Labor Safety in Industry, No. 9, C.30–36, (in Russian).

[21] **Basarir H., Bin H., Fourie A., Karrech A., Elchalakani M.,** 2018
An Adaptive Neuro Fuzzy Inference System to Model the Uniaxial Compressive Strength of Cemented Hydraulic Backfill. Mining of Mineral Deposits, No. 12(2), pp. 1-12.

[22] **Sotskov V., Dereviahina N., Malanchuk L.,** 2019
Analysis of Operation Parameters of Partial Backfilling in the Context of Selective Coal Mining. Mining of Mineral Deposits, No. 13(4), pp. 129-138.

[23] **Iordanov I., Novikova Yu., Simonova Yu., et al.,** 2020
Experimental Characteristics for Deformation Properties of Backfill Mass. Mining of Mineral Deposits, No. 14(3), pp. 119-127

[24] **Doifode S.K., Matani A.G.,** 2015
Effective Industrial Waste Utilization Technologies towards Cleaner Environment. International Journal of Chemical and Physical Sciences, Vol. 4, Special Issue, NCSC, pp. 536–540.

[25] **Kaplunov D.R., Radchenko D.N.,** 2017
Principles of Design and Selection of Technologies for the Development of Subsurface Resources, Ensuring Sustainable Development of Underground Mines. Mining Journal, No. 11, pp. 121-125, (in Russian).