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STUDYING THE VOLUMES OF INDUSTRIAL WASTE IN UKRAINE AND SUBSTANTIATING THE TRENDS IN PROCESSING ROCK MASSES OF KRYVBAS WASTE DUMPS

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ДОСЛІДЖЕННЯ ОБСЯГІВ ПРОМИСЛОВИХ ВІДХОДІВ УКРАЇНИ І ОБГРУНТУВАННЯ НАПРЯМКІВ ПЕРЕРОБКИ ГІРСЬКОЇ МАСИ ВІДВАЛІВ КРИВБАСУ

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ИССЛЕДОВАНИЕ ОБЪЕМОВ ПРОМЫШЛЕННЫХ ОТХОДОВ УКРАИНЫ И ОБОСНОВАНИЕ НАПРАВЛЕНИЙ ПЕРЕРАБОТКИ ГОРНОЙ МАССЫ ОТВАЛОВ КРИВБАССА

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Annotation. Analysis of industrial waste in Ukraine and external waste dumps of Kryvyi Rih iron-ore basin was performed, which will help single out and classify them by enclosing rock composition as well as substantiate and develop technological schemes for technogenic object processing. The statistical analysis of the state classifier data by the classified groups of waste was performed; the analysis is the basis for determining dependence of mining waste accumulation on a time factor. The analysis of geometry of Kryvbas technogenic objects made it possible to systematize places of overburden rock accumulations (dumps, worked-out spaces of the mined-out open pits, dams) and their parameters, load-carrying transportation support, and composition of the enclosing rocks. Basic directions for distributing mined rocks of technogenic objects were established. Industrial processes and their corresponding processing equipment were substantiated. The analysis of load-carrying transport flows in the conditions of Kryvbas iron-ore open pits was carried out. It allowed generalizing of certain methods for the formation of technogenic objects and places of accumulation of overburden rock and waste (internal and external waste dumps, tailing dams, worked-out open pits) as well as the enclosing rock composition (mixed and/or selective). A technological scheme for rock mass sorting and processing was developed. Power dependence of the mining waste accumulation accumulation on the time factor was established. A classification of the rock composition of technogenic objects according to the rock structure and physicochemical properties was developed. A technological scheme for processing rock mass from the technogenic areas with the extraction of useful components was developed. The use of innovative equipment in mining industry as a part of magnetic separators to process coarse rock mass helps solve a problem of industrial wastes with the minimal energy and economic costs; it also allows preparing raw material for the mesorelief restoration and land reclamation. The obtained results make it possible to expand the area of technogenic object use, increase the overall mineral mining efficiency, and reduce the environmental impact within the mining regions.

Keywords: industrial waste, technogenic objects, waste dump, processing, technological scheme.

Introduction. As a rule, the mining technologies applied in Ukraine are concentrated on the extraction of one valuable component. Such mining and processing technologies were developed and used during the period of mining industry formation. At that time, the main task was to produce the maximum amount of concentrate without consideration of the fact that natural resources are limited, and there is certain negative impact on the environment. That causes gradual accumulation of industrial waste within the specially designated places: dumps, waste piles, tailing storage facilities, and slurry storages.

The use of inexpedient mining and processing technologies has led to environmental, technological, economic and social problems:

– absence of any substantiated waste-free technologies for mining and multiproduct processing of mineral resources;

– shortage of assessment of the associate mineral content in the subsoil (balance mineral reserves and enclosing rocks), which makes it impossible to determine actual content of valuable minerals in technogenic objects;

– there is no control and record of the flow of overburden volumes, which renders impossible to determine actual content and distribution of valuable components in the bodies of technogenic objects;

– due to the inexpedient waste storage (mixing of crystalline and sedimentary rocks, storage of the off-grade minerals without their separation), there is no possibility to use specific technologies for processing sedimentary or crystalline rocks;

– deficiency of technologies for rock mass pre-processing in Ukrainian open pits results in the loss of balance and off-balance reserves;

– absence of secondary processing of old tails and sludge with the extraction of valuable components and/or use of wastes without their processing result in the shortage in empty containers for storage of cleaning rejects;

– technogenic load on the environment increases with irreversible changes in the properties and parameters of its certain components;

– negative effect on social medium of human life and activities (deteriorating ecological component of the living environment, ill health, reducing life expectancy of the population, job cuts due to the closed unprofitable enterprises etc.);

– very low rates of reclamation of disturbed lands.

The purpose of the paper is to analyse industrial wastes of Ukraine and external dumps of Kryvyi Rih iron-ore basin that will help single out and classify them by enclosing rocks as well as substantiate and develop technological schemes for processing the technogenic objects.

Current state of the problem. A lot of specialists deal with the issues of technogenic object processing: extraction of mineral rejects, development of associate minerals, cleaning of technogenic objects, restoration of mesorelief and reclamation of land surface.

The technologies for processing different technogenic objects include a mining part (extraction, re-excavation, transportation, storage) and preliminary dressing (sorting, recovery, processing). Modern stage of the development of mining industry demonstrates that there are practically no problems with the provision of mining operations with the necessary equipment (excavators, loaders, dumpers, crushers, feeders) [1-3], while effective support of pre-processing operations and formation of technological complexes require studying susceptibility of useful components as well as substantiation of the processing methods, analysis of the equipment market, and determination of qualitative and quantitative indices.

The analysis of the literature sources related to pre-processing shows that different facilities are used in technological schemes depending of physicomechanical properties of rock mass. The works by N.I. Dmytrenko, V.I. Bieloborodov represent the results of practical use of Swedish magnet and radiometric separators for magnetite quartzites. In turn, the papers by E.A. Bespoiasko, V.D. Yevtiekhov [2] show the results of analysis of using gravitational and gravitational-magnetic techniques for processing wastes generated by national manufacturers.

Paper [5] demonstrates technological schemes for processing masses of oxidized and mixed ores stored in dumps. In this context, it is proposed to process ores of underground extraction by gravitational methods – hydraulic and pneumatic skimping; the ores extracted by surface mining are proposed to process by magnetic separation in separators with a strong magnetic field with preliminary flocculation and desludging.

In terms of waste dumps of Kryvyi Rih iron-ore basin, there is a topical issue concerning the extraction of iron ore rejects. To solve this problem, attention should be drawn to the separators with a strong magnetic field with constant magnets based on Nd-Fe-B or Sm-Co alloys. The structures of such separators were designed for coarse-, medium-, and fine-crushed mass. Innovative equipment of such type is developed by the producers from Ukraine, the Russian Federation, China, and Sweden (Table 1).

Table 1 – Producers of the equipment to process strong- and weak-magnetic ores with partition size up to 450 mm

Equipment producer	**Complex**	**Partition size of the rock mass, mm**	**Complex productivity, t/h**
LLC “Research and Development Centre” MAGNIS LTD”, Luhansk, Ukraine	КМР-1.2/1.4 ВР КМР-1.8/2 КО КМР-1.8/2 С	300 – 0 350 – 0 350 – 0	355 – 500
LLC Company “ERGO PLUS”, Kaluga, Russian Federation	Line of magnetic separation; ВМС-1 (for secondary metals); ВМС-2 (sludge)	450 – 0	1500 200 10 – 200
Beijing General Research Institute of Mining and Metallurgy, China	CT-1016 CT-1416	300 – 100 400 – 0	150 – 200 200 – 350
Ma’anshan Baiyun Environment Protection Equipment Co., Ltd, China	CTDG 1515N CTDG 1214N	350 – 40	600 – 800 500
SIWEN MAGNETIC CO., Ltd, China	SD011	350 300 250	600 – 800 300 400
Sala International AB, Sweden	BSA-1224-235	300 – 0	150 – 250

In Ukraine, LLC "Research and Development Centre" MAGNIS LTD" is a leader of the pre-processing equipment supply. First, the company implemented the equipment at the research and industrial sites; further, the company implemented its equipment at the foreign open pits of JSC "Karelsky Okatysh" and Sokolov-Sarbai Mining Production Association (SSGPO). However, if pre-processing is used for diluted ore or overburden rock with rejects, the practice of its use in terms of waste dumps is not sufficient. Under the conditions of Kryvyi Rih iron-ore basin, there is the experience of rock mass processing of "Zhovtneva" mine dump.

Availability of the equipment for processing rock mass of different composition and lumpiness makes it possible to develop technological schemes and substantiate waste-free and low-waste technologies for processing technogenic objects.

Statement of the main material. Economically developed countries solve the problems of industrial wastes at the governmental level by implementing political, economic, and environmental leverages. The situations are to be controlled in a complex way:

- passing regulatory acts at the legislative level, adopting environmental standards;
- supporting resource- and energy-saving technologies with the help of systems of grants and tax reduction;
- financing scientific, design, research and industrial developments of the advanced low-waste technologies.

Ukraine also has certain state programmes aimed at implementation of "green technologies" being environmental-friendly or less harmful in comparison with the current ones. Within the framework of those programmes, the support is given to various projects of environmental protection of regions, processing of technogenic wastes, use of alternative power sources etc. Specialists of the M. S. Poliakov Institute for Geotechnical Mechanics of the National Academy of Sciences of Ukraine study the problems concerning the reduction of environmental load in mining regions. One of these problems is the development of technical solutions for disposal or use of industrial wastes: cleaning of technogenic objects, processing of rock mass with the extraction of valuable components, restoration of a mesorelief, and land reclamation, cleaning of tailing and sludge facilities, use of spaces of the mined-out open pits, etc. [6-8].

However, despite the progress of state programmes concerning the "green technologies" implementation, Ukraine is still demonstrating accumulation of huge amounts of industrial wastes. Depending on mining intensity, total volume of the accumulated industrial wastes experience certain changes by years. The results of mathematical processing of statistic data of the state Ukrainian classifier according to the classified waste groups [9] for industrial wastes of mining industry are represented graphically (Fig.1).

The analysis of the statistic data of the State Statistic Service of Ukraine [9] as for waste formation and according to the classified grouping of the State Classifier helps identify the power dependence of waste accumulation of the mining industry Q_w in terms of time factor t (Fig. 2). The studies have shown that, on average, each 10 years 2.4 bln tons of industrial waste are accumulated in Ukraine only.

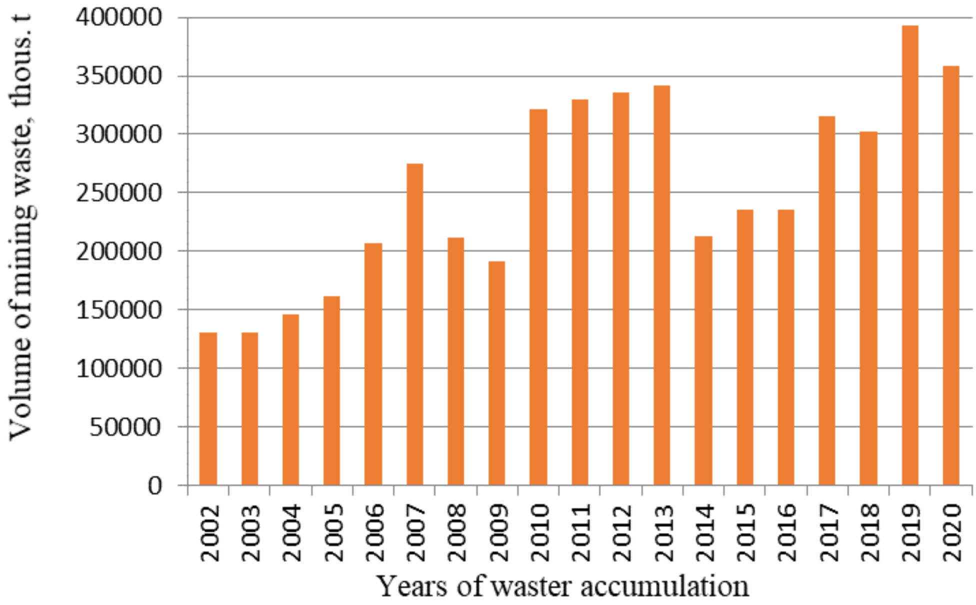


Figure 1 – Volumes of the industrial waste of Ukrainian mining enterprises by years.

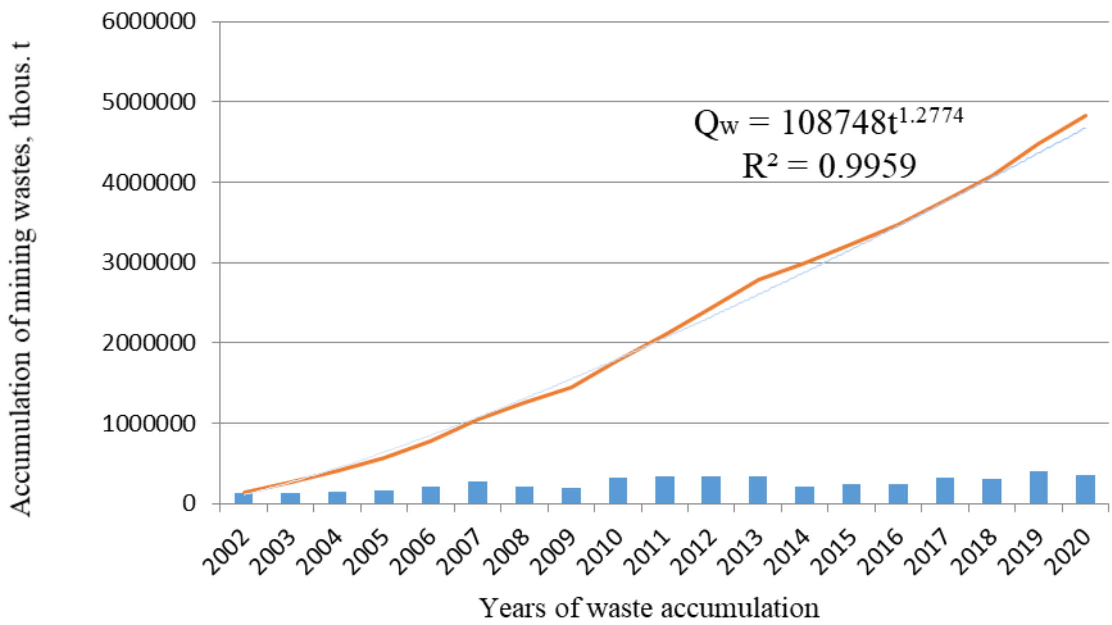


Figure 2 – Accumulation of the mining industry waste in Ukraine

The developed countries worldwide are implementing intensively different waste-free technologies of mining and processing, in terms of which all the valuable components are extracted from the mineral while waste is used to produce building materials. Such technologies exclude completely the necessity to pile and store mining and processing waste, increase resource-capacity and profitability of enterprises, provide minimum impact on the environment. Moreover, these technologies do not need any additional extraction of productive lands for dump expansion and creation of new areas for sludge (tails) accumulation. This tendency is rather prospective and topical; however, it requires great capital investment for complete technical and technological re-equipment of the production. Since numerous mining enterprises of Ukraine are at the stage of improvement, an issue concerning liquidation of technogenic objects, rock mass processing, and reclamation of the disturbed lands and areas is of growing topicality.

One of the methods to liquidate technogenic objects being a part of waste dumps and open pits or mines is the processing of external waste dumps for filling up the mined-out space and form a mesorelief [6]. Waste dumps can be cleaned with the extraction of valuable component from the rock mass; thus, the composition of enclosing rocks determines a technological complex of both extracting and processing. Thus, the iron-ore mining enterprises of Kryvbas dealing with open-pit mining were used for analysing mining schemes of the open pits and determine the corresponding places of the overburden accumulation (internal and external waste dumps, tailing dams), connections of weight transportation, pile of enclosing rocks, and available selective placing of oxidized quartzites (Table 2).

Table 2 – Distribution of the overburden rocks from the open pits of technogenic objects of Kryvyi Rih mining enterprises

Mining enterprises and open pits	**Technogenic objects**	**Transportation type**	**Enclosing rocks**
1	2	3	4
JSC Southern GZK			
Open pit of SGZK	Left-bank waste dumps	Railway electrified	Selectively: crystalline overburden rocks and oxidized quartzites
	Right-bank waste dumps (abandoned)	Motor	
PJSC “ArcelorMittal Kryvyi Rih”			
Open pit № 3	Stepovyi waste dump	Railway	Mixed: crystalline rocks and sedimentary dusty-argillaceous rocks
	Temporary waste dump № 4	Motor	Oxidized quartzites
	Waste dump № 2-3	Railway	Selectively: dusty-argillaceous within the southern and central share; oxidized quartzites within the eastern share
	Waste dump Stepovyi-2 (is under construction): – northern site – southern site	Motor	Selectively: oxidized quartzites 95%, crystalline overburden rocks 5% within the southern share
Open pit № 2-bis	Tailing dams	Railway	Crystalline overburden rocks
	Mined-out space of open pit № 1	Motor	Crystalline overburden rocks
	Distant waste dumps	Railway	Crystalline overburden rocks

Continuation of Table 2

1	2	3	4
JSC "InGZK"			
Inhuletskyi open pit	Waste dump № 1	Motor, but allowed for railway as well	Mixed composition
	Waste dump № 2	Railway	Mixed composition
	Temporary waste dump № 3 on the open pit wall	Motor	Mixed composition
JSC "Central GZK"			
Hleievatskyi open pit	Retaining prism of a tailing storage facility №1, № 2, № 3	Railway	Crystalline overburden rocks
	Internal open pit	Motor	Mixed composition
	Southern-western waste dump	Motor	Crystalline overburden rocks
	Mined-out space of open pit № 2 (backfilling)	Railway, motor	Mixed composition
	Waste dump № 6	Motor	Crystalline overburden rocks
Petrovskyi open pit	Northern waste dump	Railway (bulldozer), motor	Crystalline overburden rocks
	Eastern waste dump	Motor (bulldozer)	Crystalline overburden rocks
	Waste dump № 2	Railway (excavator)	Mixed composition
Artemovskyi open pit	Waste dump № 3	Railway (excavator)	Mixed composition
	Western waste dump	Motor (bulldozer)	Crystalline overburden rocks
JSC "Northern GZK"			
Pervomaiskyi open pit	Waste dump of Pervomaiskyi open pit	Railway	Mixed composition
	Temporary internal waste dump	Motor	Crystalline overburden rocks
	Temporary external waste dump Western	Motor	Crystalline overburden rocks
Hannivskyi open pit	Western waste dumps	Railway	Mixed composition
	Retaining prism of a tailing storage facility	Motor	Crystalline overburden rocks
	Internal waste dump over a crushing-transfer point of the conveyor ore transportation	Motor	Crystalline overburden rocks

Results and discussion. The analysis of the areas of overburden rock accumulations shows that apart from the external waste dumps the overburden rocks are fed, transported to the):

– internal waste dumps (Inhuletskyi, Hleievatskyi, Pervomaiskyi, Hannivskyi open pits) that reduces considerably the backfilling volumes in the process of future mesorelief formation and reclamation;

– mined-out space of the worked-out open pits: open pit № 1 PJSC "ArcelorMittal Kryvyi Rih" (rock mass is transported from open pit № 2-bis) and open pit № 2 JSC "CGZK" (from Hleievatskyi open pit), being already the beginning of mesorelief formation and restoration of the natural forms;

– for dam raising and construction of a retaining prism of tailing storage facilities (Hleievatskyi, Hannivskyi, and open pit № 2-bis) where rock mass is used as building materials.

The analysis of the connections of weight transportation between an open pit and areas of overburden rock accumulation demonstrates the following: internal waste dumps are formed by a motor-bulldozer method; external dumps are made by railway transport with excavator reloading; mined-out space is backfilled by means of motor transport involving a retaining prism; and tailing storage facilities are serviced mostly by railway transport with excavator reloading. Features of weight transportation during the waste dump construction influences the geometrical parameters of the final structure, which should be taken into consideration while developing technological schemes of its further clearing.

However, composition of the rocks making up a technogenic object is the key condition affecting cardinally the selection of a technology for technogenic object processing. The analysis of the enclosing rocks in the external waste dumps shows that:

– rocks are arranged selectively only in JSC "SGZK" waste dumps (crystalline overburden rocks and oxidized quartzites) and partially in waste dumps of PJSC "ArcelorMittal Kryvyi Rih": in waste dump № 2-3 within its southern and central share, there are dusty-argillaceous rocks; within the eastern part – oxidized quartzites; and in Stepovyi waste dump – crystalline overburden rocks and quartzites. The waste dumps with selective rock arrangement make up only 15 % of the total dump amount;

– external permanent waste dumps consisting only of crystalline rocks can be found at PJSC "ArcelorMittal Kryvyi Rih" (distant waste dumps) and JSC "CGZK" (southern-western, waste dump № 6, northern, eastern, western) making up 40%;

– external temporary waste dumps, which are meant to clean first of all for further development of mining operations, are made up in different ways: temporary waste dump № 4 of PJSC "ArcelorMittal Kryvyi Rih" consists only of oxidized quartzites, temporary waste dump Western of JSC "Northern GZK" is composed of crystalline rocks, and temporary waste dump № 3 of JSC "InGZK" is mixed (their influence on the per cent ratio relates to the mixed and selective ones respectively);

– external permanent waste dumps composed of crystalline and sedimentary rocks (mixed waste dumps). They are available at PJSC "ArcelorMittal Kryvyi Rih" (Stepovyi waste dump), all three waste dumps of JSC "InGZK", at JSC "CGZK" (waste dumps № 2 and № 3), JSC "Northern GZK" (waste dump of Pershotravnevyi open pit, western) make up 45 %. With relation to number and volume, it is the most common case (Fig.3).

Development of a technological scheme of industrial waste processing includes substantiation of the industrial processes and equipment, the use of which depends on rock type, rock mass value, lumpiness, and other parameters. Thus, a classification of the composition of technogenic object rocks in terms of their composition and physicomechanical properties was developed. The classification makes it possible to substantiate the use of industrial processes and equipment for developing a technological scheme of processing the rock mass from technogenic environment as well as single out its variants of application and determine the required equipment and its productivity.


Figure 3 – Construction of a waste dump involving mixed rocks

Classification of the technogenic-object rocks:

a) according to origin:

1) from an open pit:

– overburden sedimentary rock,

– overburden crystalline rock;

2) from a dressing plant:

– dry waste (dry magnetic separation of medium-crushed and fine-crushed mass),

– wet waste of a dressing process;

b) by availability of useful mineral:

– rejects of the main mineral,

– associate minerals (valuable, rare, metal, non-metal, applicable as building materials),

– no useful minerals;

c) in terms of mineral belonging to the reserves:

1) balance (rejects);

2) off-balance:

– rock from the contact zones “useful mineral – enclosing rock”,

– off-grade mineral (content of a useful component is lower than the boundary grade),

– overburden rock with ore layers or thinning, deposits being standard in their content but off-grade in their thickness,

– oxidized quartzites;

d) as for mineral type:

– standard,
– off-grade,
– oxidized;

e) according to lumpiness, the rock mass:

– requires coarse crushing (300 - 400) ÷ 1500 mm,
– coarse-crushed 100 ÷ (300 - 400) mm,
– medium-crushed 25 – 100 mm,
– fine-crushed 1 – 25 mm,
– coarse-ground 0.5 – 1 mm;
– medium-ground 0.1 – 0.5 mm;
– fine-ground 0.04 – 0.1 mm;
– extra fine-ground up to 0.04 mm;

f) in terms of possibility of selective extraction of a technogenic deposit:

– homogeneous content,
– mixed rocks,
– formation of technogenic deposits;

g) as for specific magnetic susceptibility:

– strong magnetic with specific magnetic susceptibility > $3\cdot10^{-3}$ cm^3/g;
– weak magnetic with specific magnetic susceptibility from $15\cdot10^{-6}$ to $3\cdot10^{-3}$ cm^3/g;
– non-magnetic with specific magnetic susceptibility up to $15\cdot10^{-6}$ cm^3/g.

Basing on the specified purposes and tasks, the waste dump cleaning can be performed for the following:

a) *restoration of a mesorelief*, i.e. backfilling of the mined-out space of the open pits with the rock mass. This method includes several stages [6]: first, deep open pit levels are filled with the rock mass up to the depth of the restoration of a water-bearing level (the mass requires no additional treatment like crushing, mass homogeneity). It can be crystalline, sedimentary, or mixed rock. Next, argillaceous rocks are taken to create a confining layer, above which a water-bearing level is constructed, made of sandy and crystalline rocks; above that layer, the basis of a fertile layer is restored with the help of sedimentary rock.

b) *extraction of balance and off-balance rejects* or minerals, off-grade fractions, or associate useful components from the industrial waste [10]. Processing of the rock mass of technogenic objects requires thorough selection of the rock mass according to its composition, homogeneity, and lumpiness. Depending of the value and fraction size of the component, different technological schemes can be elaborated: both for sedimentary and crystalline rocks. Mixed rocks require more problematic (considered) and multi-stage scheme. For instance, if a technogenic object is represented by a waste dump of oxidized quartzites, then a technological scheme of mineral processing includes the following: production processes of mining operations consisting of extraction, transportation, and preparation of the rock mass (by crushing) as well as preliminary dressing (extraction of barren rock and /or magnetite quartzites), which helps prepare the rock mass for its further use or extract valuable / hazardous components.

c) *reclamation of disturbed lands* includes a complex of technical solutions aimed at cleaning of technological objects, liquidation of the aftereffects of the disturbed lands, and restoration of a fertile layer of the land area [11, 12].

Cleaning of the external crystalline-rock waste dump can be performed in different ways:

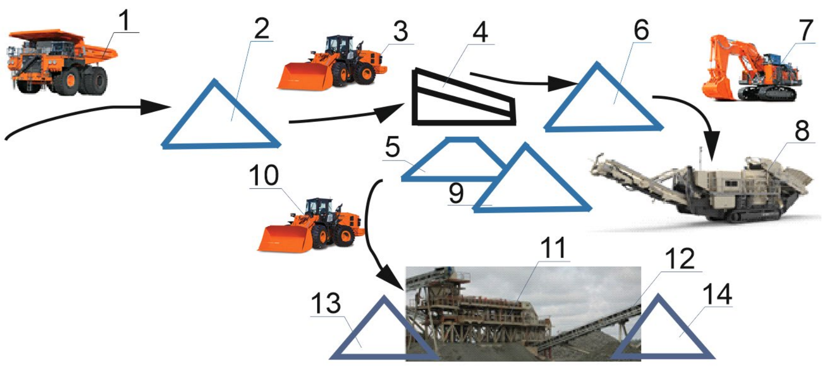
1) extraction of the rock mass without its further processing;

2) extraction of the rock mass with its further processing according to a uniform technological scheme;

3) selective extraction of the rocks (from the rock mass), having the greatest share of useful components with its further processing by means of a mobile crushing and screening plant;

4) selective extraction of the rocks (from the rock mass), having the greatest share of useful components with its further processing with the help of a semistationary crushing and screening plant.

An external waste dump is constructed within the period of several decades along with the development of mining operations in an open pit. The dump is formed in tiers being from 10 m to 20 m high. After its breaking by blasting, the crystalline rock mass with the lumpiness of 1200 (1500) mm is delivered from an open pit into a waste dump. That is why its processing requires preliminary preparation in terms of granulometric composition according to the mechanical characteristics of separators. The rock mass can be prepared by two methods: by screening, crushing or by two technique simultaneously. Use of screening in a technological scheme allows selecting the rock mass of the required fraction; however, in this case the oversize product is transported to waste, which is not economical and rational. Moreover, use of crushing for all the rock mass is not always efficient, especially when the equipment capacity is limited in its productivity. Consequently, a technological scheme with the complete cycle of rock mass preparation by its granulometric composition is developed (Fig.4).



1 – dump truck, 2 – dump of rock mass for a pre-processing complex, 3 – loader, 4 – screening machine, 5 – through product, 6 – oversize product, 7 – excavator, 8 – coarse crusher, 9 – crushed rock mass, 10 – loader, 11 – pre-processing complex, 12 – transfer conveyer, 13 – dump of industrial products, 14 – waste dump

Figure 4 – Schematic of a technological complex of the equipment for processing crystalline rocks of a waste dump

The proposed scheme means selective extraction of dump waste with the greatest content of useful components with the processing in a semistationary crushing and screening plant. Dump trucks *1* transport the selected rock mass into the dump *2*, from where it is loaded on screening machines *4* with the help of a loader *3*. The screening machines sort the rock mass by its lumpiness. The oversize product is sent into dump *6*, from where excavators *7* load it into coarse crusher 8 coarse crusher *8*. The crushed rock mass *9* and undersize product *5* are loaded by loader *10* into the ore-collecting complexes "MAGNIS KMR" *11* with the separators for coarse-crushed mass. The industrial product is transported with the help of a conveyer *11* into a dump *13*; the non-magnetic product is sent into a dump *14*.

The proposed technological scheme can be also used during the continuous waste dump operation at the ingoing freight flow to extract rejects or during the waste dump cleaning and mesorelief formation.

Conclusion. The performed analysis of the statistic data of the State Statistic Service of Ukraine in terms of waste formation based on the classified grouping of the State Classifier makes it possible to identify the power dependence of the mining waste accumulation basing on a time factor. The time factor shows that 2.4 bln tons of industrial wastes are accumulated each year only in Ukraine.

To solve the problem with industrial waste in Ukraine, a complex state-level approach is required based on the implementation of political, economic, and environmental leverages by adopting regulatory acts and environmental standards as well as supporting various research and design developments aimed at both creation of perspective resource-saving and low waste technologies and control of their implementation.

A classification of rock composition of technogenic objects was developed according to its content and physicomechanical properties. The classification helps substantiate the use of industrial processes and equipment for developing a technological scheme for processing the rock mass of technogenic objects, highlight its variants of application, and determine the necessary equipment along with its productivity.

The accumulation areas of the overburden rocks of Kryvyi Rih iron-ore basin open pits were analyzed. The analysis shows that the overburden rocks are dumped in the internal and external waste dumps, mined-out spaces of the worked-out open pits, for dam raising and construction of a retaining prism of a tailing storage facility. As for composition, the waste dumps with partial selective arrangement of rock make up only 15% of general dump number; external permanent waste dumps consisting only of crystalline rocks account for 40%; and mixed waste dumps make up 45%.

The use of innovative equipment in mining industry as a part of magnetic separators to process coarse rock mass helps solve a problem of industrial wastes with the minimal energy and economic costs; it also allows preparing raw material for the mesorelief restoration and land reclamation. Use of constant-magnet separators with increased inductivity makes it possible to improve the quality of extracted components along with the decrease of power consumption.

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Анотація. В статті виконано аналіз промислових відходів України і зовнішніх відвалів Криворізького залізорудного басейну, що дозволить виділити і класифікувати їх за складом вміщуючих гірських порід для обґрунтування і розробки технологічних схем переробки техногенних об'єктів. Статистичний аналіз даних державного класифікатора за класифікаційними групами відходів дозволив встановити залежність накопичення відходів гірничодобувної промисловості від часового чинника. Гірничо-геометричний аналіз техногенних об'єктів Кривбасу дозволив систематизувати місця накопичення розкривних порід (відвали, вироблений простір відпрацьованих кар'єрів, дамби) і їх параметри, вантажотранспортне забезпечення та склад порід, що вміщуються. Встановлено основні напрямки розподілу гірничої маси техногенних об'єктів. Обґрунтовано виробничі процеси і відповідне їм обладнання для їх переробки. Виконано аналіз вантажотранспортних потоків в залізорудних кар'єрах Кривбасу. Аналіз дозволив узагальнити способи формування техногенних об'єктів, місця складування розкривних порід і відходів (зовнішні і внутрішні відвали, дамби хвостосховищ, відпрацьовані кар'єри) і склад порід, що вміщують (змішані і / або селективні). Розроблено технологічну схему розбирання і переробки гірничої маси. Встановлено ступеневу залежність накопичення відходів гірничодобувної промисловості від часового фактору. Розроблено класифікацію складу гірських порід техногенних об'єктів за структурою і фізико-механічними властивостями гірничих порід. Розроблено технологічну схему переробки гірничої маси з техногенних середовищ з вилученням корисних компонентів. Розроблено технологічну схему переробки гірської маси з техногенних середовищ з вилученням корисних компонентів із застосуванням інноваційного обладнання, що дозволяє вирішити проблему промислових відходів з мінімальними енергетичними та економічними витратами, а також дозволяє підготувати сировину для відновлення мезорельєфу та меліорації земель. Отримані результати дозволяють розширити сферу застосування техногенних об'єктів, підвищити ефективність видобутку корисних копалин і знизити вплив на екологічну ситуацію в гірничодобувних регіонах.

Ключові слова: промислові відходи, техногенні об'єкти, відвал, переробка, технологічна схема.

Аннотация. В статье выполнен анализ промышленных отходов Украины и внешних отвалов Криворожского железорудного бассейна, что позволит выделить и классифицировать их по составу вмещающих горных пород для обоснования и разработки технологических схем переработки техногенных объектов. Статистический анализ данных государственного классификатора по классификационным группам отходов позволил установить зависимость скопления отходов горнодобывающей индустрии от временного фактора. Горно-геометрический анализ техногенных объектов Кривбасса позволил систематизировать места накопления вскрышных пород (отвалы, производимое пространство отработанных карьеров, дамбы) и их параметры, грузотранспортное обеспечение и состав вмещающих пород. Установлены главные направления распределения горной массы техногенных объектов. Обоснованы производственные процессы и соответствующее им оборудование для их переработки. Выполнен анализ грузотранспортных потоков в железорудных карьерах Кривбасса. Анализ позволил обобщить способы формирования техногенных объектов, места складирования вскрышных пород и отходов (наружные и внутренние отвалы, дамбы хвостохранилищ, отработанные карьеры) и состав вмещающих пород (смешанные и/или селективные). Разработана технологическая схема разборки и переработки горной массы. Установлена степенная зависимость накопления отходов горнодобывающей промышленности по временному фактору. Разработана классификация состава горных пород техногенных объектов по структуре и физико-механическим свойствам горных пород. Разработана технологическая схема переработки горной массы из техногенных сред с извлечением полезных компонентов. Разработана технологическая схема переработки горной массы из техногенных сред с извлечением полезных компонентов с применением инновационного оборудования, что позволяет решить проблему промышленных отходов с минимальными энергетическими и экономическими затратами, а также позволяет подготовить сырье для восстановления мезорельефа и мелиорации земель. Полученные результаты позволяют расширить область применения техногенных объектов, повысить эффективность добычи полезных ископаемых и снизить влияние на экологию в горнодобывающих регионах.

Ключевые слова: промышленные отходы, техногенные объекты, отвал, переработка, технологическая схема.

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