Technological Solutions for Increasing the Efficiency of Beneficiation Processes at the Mining of Titanium-Zirconium Deposits

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Abstract

The article is devoted to the issue of effective use of associated minerals at the development of titanium-zirconium ore deposits. Since deposits of sedimentary titanium-zirconium ores have large areas, hundreds of million tons of mining mass are transformed into man-caused formations during their exploitation. Of the entire volume of mining mass, only 1% after beneficiation is used for the production of metal titanium, the rest of the mining rocks are stored in dumps and tailings. The use of resource-saving technological solutions at the development of these deposits allows obtaining loam, clay and sand as accompanying minerals. They can be used for the manufacture of brick products, molding and construction sand, sub-base layers in construction works and cosmetic materials. A significant part of sand and clay rocks in titanium-zirconium deposits is in a mixed state and cannot be effectively used without additional a technological solution, that is why it is placed in bulk tailings storage facilities. The article provides the rationale solutions for resource-saving technological that allow during the process of titanium-zirconium ores beneficiation to separate clay rocks from sand within the pit, which allows to obtain additional volumes of titanium-zirconium components and associated minerals for the building industry and reduce the land area required for the location of tailings storage facilities.

Keywords: *surface mining, titanium and zirconium deposits, mining technology, ore beneficiation, accompany minerals*

1. Introduction

The development of new and existing titanium-zirconium deposits of Ukraine is of strategic importance for the development of the economy, as it allows providing the needs of many sectors of the economy with scarce raw materials. Up to 10% of the world's reserves of titanium-zirconium ores are concentrated in the depths of Ukraine, which makes it an influential player on the world market. The importance of titanium-zirconium ores is extremely important for high-precision branches of the economy, since they have a wide range of applications in aircraft construction, in the production of rockets, electronics, high-precision devices, medical equipment, etc. Every year, the extraction of titanium-zirconium ores provides Ukraine with revenues to the economy in the amount of 3–4 billion Euros, which allows for high tax revenues and ensures the sustainable development of the economic and social sphere [1].

In addition to the significant economic effect of the development of placer titanium-zirconium mineral deposits, there is a certain list of problematic issues. First of all, this is the need to set aside significant land areas for the exploitation of pits, as well as the location of dumps and tailings storage facilities [2]. The main feature of the development of this type deposits is the insignificant content of useful minerals in the ore layer (an average of 8% by mass), which requires significant costs for the movement of ore pulp and the storage of beneficiation waste in external tailings. Since the productivity of this group pits is 3–5 million cubic meters per year, the accumulation of landfill waste occurs on a significant scale. This leads to the fact that the volumes of their accumulation lead to a critical level of filling of tailings storage facilities. For example, the total area of Vilnohirsky MMP tailings is 770 hectares, in which more than 250 million m³ of solid waste from beneficiation production was placed during the years of enterprise operation [3].

The second problem that has emerged acutely for the titanium industry of Ukraine today is the depletion of large deposits of minerals with relatively simple hydrogeological conditions of occurrence, which requires involvement in the development of new deposits with complex mining and geological problems. For the organization of sustainable extraction, technological and organizational tasks related to significant volumes of water inflow must be solved. The development of new deposits is also accompanied by the formation of a significant amount of production waste, which requires large areas for the location of tailings storage facilities. For example, during the operation of the new pit of the Motronivsky MPP, the share of useful minerals in the ore is 5%, and in the volume of the mining mass – about 1%. During the operation of this pit using the old technology, the total volume of production waste will be 830 million m³ with the volume of titanium-zirconium minerals – 7.5 million m³.

2. Analyzes of conducted researches

Increasing the level of resource conservation at the development of titanium deposits is possible due to the separation

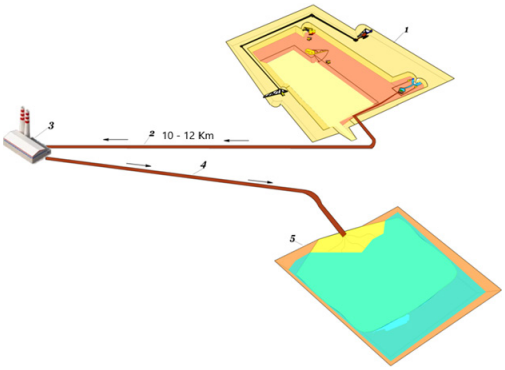

Fig. 1. The existing technological scheme for the development and beneficiation of titanium-zirconium ores at the Vilnohirsky MMP: 1 – pit, 2 – ore (mineral fraction content 8%); 3 – beneficiation plant; 4 – processing waste (tails 92%: clay 20%, quartz sand 70%, mineral fraction 2.55%); 5 – tailings storage

Rys. 1. Istniejący schemat technologiczny zagospodarowania i wzbogacania rud tytanowo-cyrkonowych w Vilnohirskim MMP: 1 – odkrywka, 2 – ruda (zawartość frakcji mineralnej 8%); 3 – zakład wzbogacania; 4 – odpady przeróbcze (odpady 92%: glina 20%, piasek kwarcowy 70%, frakcja mineralna 2,55%); 5 – zbiornik odpadów poflotacyjnych

of contained in ore sand and clay rocks with their subsequent separate storage in order to prevent the need to create a tailings repository. The research carried out in the work [4] is devoted to the issue of formation of hydraulic dumps from contained sand-clay rocks of the ore layer with low filtration properties. In order to solve the problem of low filtration properties of rocks an additional process of cleaning containing rocks from clay using a hydromechanical method of separation is proposed. The authors of [5], who studied the separation of sand-clay rocks using a special sand washing device, also studied the process of separation of the containing rocks of the ore layer. The developed method allows separating particles of quartz sand from clay rocks within the limits of the pit field due to the compact dimensions of the installation. To optimize the separation process it can be installed on a concentrator which is located inside of the pit [6].

Part of the scientific and research work is devoted to the formation of the internal dump pit from sand containing rocks by the hydromechanization method [7]. The formation of the internal hydraulic dump from quartz sand occurs in tiers using a hydro-mechanized method. Thus, after washing the lower dump layer the rocks of the upper dump layers are deposited on its surface by a mechanized method. The results of research [8] made it possible to establish the order of separation of sand from clay, followed by sending the clay to the gravity thickener. This process allows for thickening, after which the clay is safely stored in the rock dump, thereby forming a man-made resource for the future [9].

A significant shortcoming of these works is the field of application of research results, because there are no specific studies on establishing effective parameters for the storage of associated raw materials in man-made formations on the surface of internal dumps during pit development [10]. The reason is that the accompanying raw materials, which are represented by clays, as a rule, are not considered as a resource that is promising for future use. Because of this, clays are stored in bulk in dumps or tailings, which leads to their loss from the point of reuse.

3. Establishing unresolved problems

Solving the existing problems of the development of titanium-zirconium deposits in complicated hydrogeological conditions can be achieved by improving the processes of extracting and enriching the mineral with the aim of creating a closed cycle of obtaining titanium-zirconium raw materials at the mining enterprise. At the same time, it should be taken into account that the placement of the sandy mixture in the lower level of the internal dump and the clay mixture in the man-made deposit on the side of the pit will allow to reduce the volume of haulage work in the pit due to the reduction of the volume of haulage of the containing rocks of the ore layer to the stationary concentration plant, as well as speed up the process of reclamation of disturbed lands, since there is no need to wait for the end of the term for the formation of the tailings storage facility.

4. Tasks Settings

The aim of conducted researches is creation of a closed cycle of obtaining titanium-zirconium raw materials at a mining enterprise by establishing technological parameters for the development placer deposits with the separation of containing rocks at a concentration plant of collective concentrate. To achieve the aim, the following tasks were solved: research of the existing technology parameters at the development of titanium-zirconium deposits; conduct an analysis of the resources of titanium ore beneficiation technology with the existing field development technology; determine the characteristics of the man-made deposit formed in the tailings; to study the possibility of involving mineral resources of tailings in the closed cycle of the enterprise; to develop technological solutions for the creation of a waste-free technology for the development of titanium-zirconium deposits with the repeated involvement of beneficiation waste in the production process.

5. Improvement of existing mining technology of titanium-zirconium raw materials

The existing development and beneficiation technology at the Vilnohirsky MMP is implemented by means of hydraulic washing and supplying the mineral to the beneficiation plant. Sustainable operation of the enterprise using this technology requires the use of significant water resources. On average, in one year of operation, about 10 million tons of ore is supplied to the beneficiation plant, which requires the use of more than 30 million m^3 of water. The total cost of hydrohaulage of ore

Fig. 2. Concentrated release of tails from the pulp duct
Rys. 2. Skoncentrowane uwalnianie odpadów

Fig. 3. Release of tailings from hydrocyclones
Rys. 3. Zrzut odpadów poflotacyjnych z hydrocyklonów

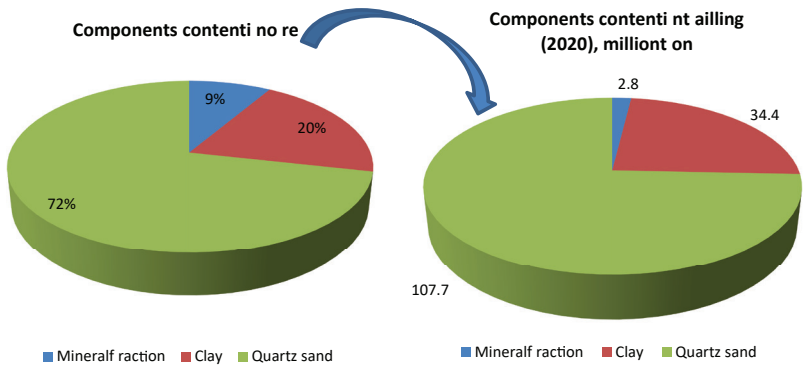

Fig. 4. Comparison of the useful components content in ore and tailings during the development of the Vilnohirsky MMP pit
Rys. 4. Porównanie zawartości składników użytecznych w rudzie i odpadach poflotacyjnych podczas robot przygotowawczych w Vilnohirsky MMP

sands for a length of more than 10 km from the pit to the beneficiation plant amounts to more than 5.1 million Euros per year.

In addition, about 100 million m³ of water per year is supplied to the beneficiation plant at all stages of ore separation and gravity haulage of tailings. The costs of providing such technology with water amount to more than 3.8 million Euros per year. The need to use such large volumes of water to haulage ore sands to the beneficiation plant is due to outdated technology. The main consumption of water is explained by the lack of division of tailings into clay and sandy components with further thickening (Fig. 1). This process is accompanied by the pumping of more than 80 million m³ of beneficiation tailings into tailings storage facilities, which consumes about 43 million kW per year, or 2.9 million Euros.

With the average cost of haulage 1 m³ of tailings – 0.05 Euro the total costs for this process are about 4.0 million Euro per year. The amount of floating tailings is about 30 million m³. Thus, on average, the volume of waste from the beneficiation plant at the Vilnohirsky MPP is about 110 million m³ per year. Due to the imperfection of the beneficiation process, a certain part of the mineral fraction falls into the tailings reservoir, which is formed by a hydromechanical method (Figs. 2, 3).

The necessity of forming a tailings storage facility (Fig. 2) is related to the physical and mechanical properties of the containing rocks. These rocks are represented by a sand-clay mixture and have low filtration properties, which do not allow them to form a stable slope of the inner dump layer by hydromechanical method with the existing technology.

The process of forming tailings in Ukraine is regulated by the "State Waste Classifier DK 005-96", and tailings are solid, fine-grained particles belonging to the IV hazard class (low-hazard waste).

Under the conditions of the Vilnohirsky MMP, due to the imperfect beneficiation technology, up to 3% of the mineral fraction from the ore is lost and together with the sand-clay mixture, enters the tailings repository (Fig. 4). Thus, the process of stacking the beneficiation tailings in the tailings storage is a process of forming a man-made deposit that is prospect of further processing.

After the tailings deposit has already been formed, the mineral fraction contained in it must be accounted for. The composition of man-made formations of beneficiation tailings is recorded annually in accordance with the "Instructions on the Procedure for Maintaining the State Balance of Solid Minerals Stocks". Together with this procedure the characteristics of the man-made deposit formed in the bowl of the tailings storage facility are determined (Table 1).

In order to perform the tasks related to the protection of the subsoil and the complex use of minerals in the formation of man-made formations, the geological surveying service of enterprises must provide:

- control of storage and saving of sand-clay beneficiation waste in tailings in accordance with the requirements of the Code of Ukraine "On Subsoil";
- accounting for the movement of waste tailings from beneficiation production, which are sent to tailings storage facilities for the formation of a man-made deposit, which contains useful components that are temporarily not used, in accordance with the current regulatory documents;
- execution of geological and geological-exploration works at the sites of tailings storage facilities according to approved projects.

Tab. 1. Characteristics of the man-made deposit formed in the tailings basin

Tab. 1. Charakterystyka złoża antropogenicznego utworzonego w osadniku

Factors	Indexes
1. Method of formation	Hydraulic method of formation
2. Morphological feature	Bulk, which is formed when filling low ground of the day surface
3. Composition	Rock, consisting of natural rocks and represented by sand-clay material
4. Possibility of use	Extraction of ilmenite, rutile and zircon, as well as extraction of disten, sillimanite and staurolite
5. Environmental impact	Safe, represented by sand and clay fractions that are weakly destroyed during storage

Fig. 7. Development of man-made deposit of titanium-zirconium ores by hydromechanized method

Rys. 7. Rozwój antropogenicznego złoża rud tytanowo-cyrkonowych metodą hydromechanizowaną

Fig. 8. Beneficiation plant of titanium-zirconium ores from man-made deposits

Rys. 8. Zakład wzbogacania rud tytanowo-cyrkonowych ze złóż antropogenicznych

A detailed study of the mineral composition of the Vilnohirsky MMP tailings made it possible to determine that with the existing technology of titanium-zirconium ores beneficiation, the tails contain from 1 to 3% of the final amount of the main components: zircon, rutile, ilmenite and related ones: disten, sillimanite, staurolite (Fig. 5).

According to the conducted studies, it was established that during the titanium-zirconium deposits development up to 25% of valuable minerals fall into the tailings. Thus, a new man-made resource with a rich content of mineral raw materials is created. According to a preliminary estimate, there may be mineral resources worth up to 1 billion Euros within the Vilnohirsky MMP tailings storage facility (Fig. 6).

The tailings deposits, formed as a result of Vilnohirsky MMP activities, were transferred to the status of man-made deposits, which allows another company to extract titanium-zirconium raw materials from them. The development of these deposits is carried out by a hydromechanized method with the subsequent extraction of valuable components at the beneficiation plant (Figs. 7, 8). Thus, the imperfection of the beneficiation technology organization leads to financial losses. According to preliminary estimates, the involvement of auxiliary resources of the raw material base of a mining enterprise (on the example of Vilnohirsky MMP) at the expense of the mineral components of the tailings repository (which was formed over 50 years) would increase the value of the raw material base of the enterprise by $1.0 billion.

The scheme of mining mass beneficiation from the tailings depository involves the use and placement of a collective concentrate beneficiation plant near the tailings depository (Fig. 8). The collective concentrate obtained after preliminary beneficiation is sent to the main beneficiation plant.

The processing of titanium-zirconium components from tailings is a more efficient process compared to the development of a natural deposit. Since during the development of the latter, along with the formation of large volumes of waste placed in the tailings repository, an additional disadvantage is the need to haulage the entire volume of useful mineral to a stationary beneficiation plant (10–12 km), which, provided that 90–95% of the containing rocks in ore causes a significant volume of excess haulage work.

The cost of obtaining a collective concentrate during the development of a man-made titanium-zirconium deposit at a wet beneficiation plant located near the tailings storage facility is 48.5 Euros/t, which is more than 4 times less (due to the reduction in the use of energy carriers, volumes of hydropulp and tailings haulage, amount of water) than when receiving a collective concentrate at the main concentration plant (231 Euro/t), which is located on the industrial site of the plant at a distance of up to 10 km.

It is worth noting that today, in connection with the improvement of beneficiation technologies, reprocessing of tailings is possible within the scope of the existing main enterprise. Therefore, according to the Laws of Ukraine, beneficiation tailings are not classified as waste. In this regard, the easiest solution to implement is proposed, which will allow to attract mineral resources of tailings storage facilities into the closed work cycle of the enterprise (Fig. 9).

6. Development of the closed cycle concept of titanium-zirconium raw materials mining

The presented technological scheme (Fig. 9) is the most effective for titanium-zirconium pits that have been in operation for a long time and have managed to accumulate significant mineral resources in the tailings repository, and the involvement of mineral raw materials from the tailings repository in the closed work cycle of the mining and beneficiation complex allows to reduce the cost obtaining a collective concentrate of titanium minerals up to 40%. However, the use of this technology in the operation of existing and new pits has a number of significant disadvantages. First of all, it requires large areas of free land for the location of the tailings storage facility, secondly, its operation requires the construction of a system of enormous length pipelines, and thirdly, the need to supply the plant with the entire volume of useful mineral remains. As already noted earlier, on average only 5% of the total volume of ore consists of titanium-zirconium minerals, the delivery of which is necessary to a stationary beneficiation

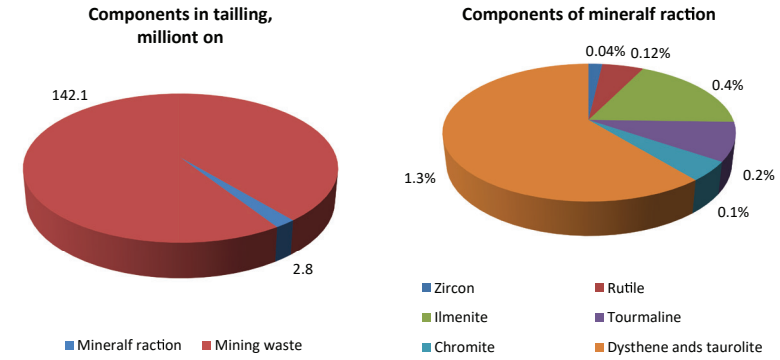

Fig. 5. The content of valuable useful components in the man-made deposit

Rys. 5. Zawartość cennych składników użytkowych w złożu antropogenicznym

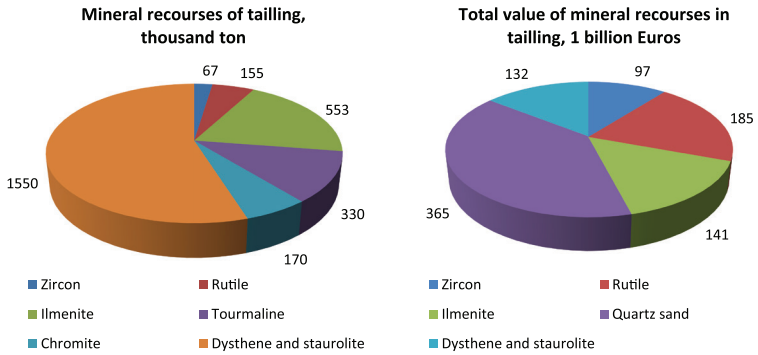

Fig. 6. Projected value of mineral resources in the Vilnohirsky MMP tailings

Rys. 6. Prognozowana wartość zasobów mineralnych w odpadach poflotacyjnych w Wilnohirskim MMP

plant. The above-mentioned problems also lead to a low level of integrated use of associated minerals in the enterprise's production activities, which prompts the search for new technological solutions [11]. In this regard, when developing new titanium-zirconium deposits, there is a critical need to develop a technological scheme that will allow reducing the area of tailings storage facilities and reducing the volume of haulage work during the operation of the mining and beneficiation plant.

The proposed technological scheme is primarily aimed at creating a waste-free technology for the development of new titanium-zirconium deposits with the possibility of re-involving beneficiation waste into the production process (Fig. 10).

The implementation of the technological scheme (Fig. 10) is carried out by building a beneficiation plant of collective concentrate on board the pit, which receives 100% of titanium-zirconium ore from the pit. Mined ore in the form of pulp enters the collective concentrate plant, where ore beneficiation and distribution of ore pulp into rough concentrate (up to 7%), clay fraction beneficiation tails (up to 20%), and sand beneficiation tails (up to 72%) take place in parallel. The crude concentrate is transported to a stationary concentrator through a pulp pipeline [12]. The tailings of clay fraction beneficiation are carried through the pulp pipeline to the thickener, which is located in the immediate vicinity of the pit, where the clay is thickened with the subsequent placement of accompanying raw materials in the man-made deposit. Sand beneficiation tailings are pumped through the slurry pipeline to the second part of the internal hydro dump from the non-working slope of the pit. Due to the separation of clay from sand, the resistance of the dump layers to landslides is ensured and it is possible to place new dump layers on their surface mechanically [13].

The main feature of the proposed technology is the separation of sand-clay containing rocks for the purpose of their further separate storage in the residual space of the pit. However, the most difficult task is the handling of clay, which after beneficiation is in a watered form and dries for a long time in natural condition. To solve this problem, it is worth turning to world experience, because today there are effective technologies for thickening waste from beneficiation factories. They are widely used in the Timmins, Langmuir Mine in Canada [14], in the USA – in the Blue mine Hills, at the mining in South Africa (Fig. 11).

The application of the tailings separation technology into clay and sand components with their subsequent thickening (Fig. 11) allows to significantly reducing the amount of mining waste. For example, when 10 million tons of ore are fed to the beneficiation plant of Vilnohirsky MMP, only 0.6 million tons (6–7%) of useful minerals are extracted and the remaining waste (9.4 million tons) is a sand-clay mixture in a liquid state. During the separation of the sandy and clay mixture, 70% of the water (16.5 million m^3) is found in the sandy tailings and 50% (1.77 million m^3) in the clay tailings when they are thickened. Thus, according to the proposed technology, the amount of tailings of the beneficiation plant will be reduced to 22.7 million m^3, which is more than four times less than with the existing technology. At the same time, the savings in electricity costs only due to the pumping of waste to the tailings storage facility will amount to about $1 million/

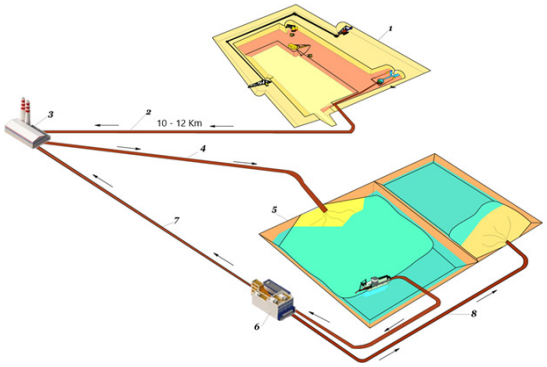

Fig. 9. Technological scheme for the development of a titanium-zirconium deposit with the involvement of mineral resources of the tailings repository: 1 – pit; 2 – ore (mineral fraction content 8%); 3 – beneficiation plant; 4 – processing waste (tails 92%: clay 20%, quartz sand 70%, mineral fraction 2.55%); 5 – tailings storage facility; 6 – concentration plant of collective concentrate; 7 – collective proofing concentrate (2.3%); 8 – tailings (sand-clay mixture)

Rys. 9. Schemat technologiczny zagospodarowania złoża tytanowo-cyrkonowego z udziałem surowców mineralnych składowiska odpadów: 1 – odkrywka; 2 – ruda (zawartość frakcji mineralnej 8%); 3 – zakład wzbogacania; 4 – odpady przetwórcze (odpady 92%: glina 20%, piasek kwarcowy 70%, frakcja mineralna 2,55%); 5 – obiekt składowania odpadów poflotacyjnych; 6 – zakład zagęszczania koncentratu zbiorowego; 7 – zbiorczy koncentrat wzmacniający (2,3%); 8 – odpady przeróbcze (mieszanka piasku i gliny)

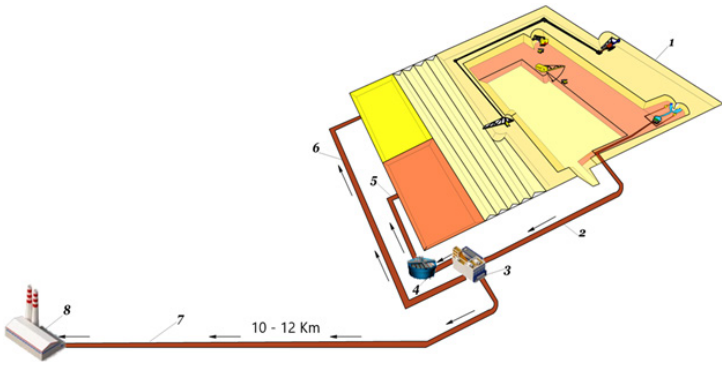

Fig. 10. Technological scheme for the closed cycle mining of a titanium-zirconium deposit: 1 – pit; 2 – ore (8% mineral fraction); 3 – concentration plant of collective concentrate; 4 – clay thickener; 5, 6 – processing waste (clay 20% of the volume of ore, quartz sand – 72%, respectively); 7 – mineral fraction 7%; 8 – beneficiation plant

Rys. 10. Schemat technologiczny eksploatacji złoża tytanowo-cyrkonowego w obiegu zamkniętym: 1 – odkrywka; 2 – ruda (8% frakcji mineralnej); 3 – zakład zagęszczania koncentratu zbiorczego; 4 – zagęszczacz gliny; 5, 6 – odpady przetwórcze (glina 20% objętości rudy, piasek kwarcowy – odpowiednio 72%); 7 – frakcja mineralna 7%; 8 – zakład wzbogacania

year. A comparison of the main technical and economic indicators of the existing and proposed technological schemes is given in the table. 2.

In addition to the economic effect of reducing operational costs, the use of modern equipment allows for additional extraction of conditioned zircon, rutile and ilmenite concentrates and aluminosilicates (dysthene, staurolite) from the ore layer. The rates of beneficiation according to modern schemes are quite high and the extraction of commercial concentrates from the original ore reaches 95–98%.

Thus, the implementation of the proposed technological scheme for the development of titanium-zirconium deposits allows obtaining three significant advantages. First, there is the possibility of selective separation of sand from clay, after which separate man-made deposits are formed from the clay; secondly, due to the separation of clay from sand, there is an opportunity to stack sand in the internal dump of the pit with the subsequent placement of dump layers on its surface by a mechanical method. And as a result, due to the mechanical formation of the upper dump layers, it is possible to significantly reduce the area of external tailings storage facilities. Thus, compared to other technological solutions, up to 20% of clay and 72% of quartz sand will be selectively extracted from 92% of the sand-clay mass. All the sand is placed in the internal dump of the pit and the man-made deposit of building raw materials is formed from the clay, which will be involved in further use.

7. Conclusions

The carry out researches confirm the effectiveness of the proposed technology for the development of a titanium-zirconium deposit with a closed cycle. Its implementation makes it possible to ensure cost-effective and practically ecologically clean and waste-free production with a significantly lower cost of the main products of existing mining and beneficiation enterprises. In this way, the task of the circular economy of mining production is implemented, which consists in expanding the possibilities of using renewable resources (waste from beneficiation production) and creating cycled technological schemes with multiple use of water at the development of a titanium-zirconium deposit.

It has been proven that the repeated extraction of mineral raw materials from man-made deposits (tailings) of already existing mining and beneficiation plants will help to minimize economic damage to the environment. It was established that for the operating conditions of the Vilnohirsky MMP, the ap-

Fig. 11. Installation for thickening beneficiation waste

Rys. 11. Instalacja do zagęszczania odpadów

Tab. 2. Comparison of technological schemes for the development of titanium-zirconium deposits

Tab. 2. Porównanie schematów technologicznych udostępnienia złóż tytanowo-cyrkonowych

Indicator	Existing technological scheme	The proposed technological scheme
Hydrohaulage of ore to the beneficiation plant:		
- share of the total mass of ore, %	100	7
- volume, million tons	10	0.7
- costs, million Euros	5.15	0.36
Hydrohaulage of beneficiation tailings:		
- distance, km	6	0.5
- costs, million Euros	4.0	0.33
Annual economic effect, EUR million	-	8.5

plication of the proposed technological solutions will reduce the area for the location of tailings storage facilities by 4 times.

It was proved that the proposed solutions allow reducing the cost of the main products of the mining and beneficiation plant due to additional volumes of mineral raw materials extraction from man-made resources by 30–40% and additional creation of man-made deposits of building raw materials. The implementation of such an approach is connected with the use of the most important principle of creating environmentally safe technologies of mining production – the organization of a closed technological cycle of the mining enterprise.

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Rozwiązania technologiczne zwiększające efektywność procesów wzbogacania w eksploatacji złóż tytanowo-cyrkonowych

Artykuł poświęcony jest zagadnieniu efektywnego wykorzystania minerałów towarzyszących przy zagospodarowaniu złóż rud tytanowo-cyrkonowych. Ponieważ złoża osadowych rud tytanowo-cyrkonowych mają duże powierzchnie, setki milionów ton masy wydobywczej podczas ich eksploatacji przekształcane są w formacje antropogeniczne. Z całej masy wydobywczej zaledwie 1% po wzbogacaniu jest wykorzystywane do produkcji tytanu metalicznego, reszta skał wydobywczych składowana jest na hałdach jako odpady poflotacyjne. Wykorzystanie zasobooszczędnych rozwiązań technologicznych przy zagospodarowaniu tych złóż pozwala na uzyskanie iłów, glin i piasku jako kopalin towarzyszących. Mogą być one stosowane do produkcji wyrobów z cegły, piasku formierskiego i budowlanego, warstw podkładowych w budownictwie oraz materiałów kosmetycznych. Znaczna część skał piaskowych i ilastych w złożach tytanowo-cyrkonowych jest w stanie wymieszanym i nie może być efektywnie wykorzystana bez dodatkowego rozwiązania technologicznego, dlatego jest umieszczana na składowiskach odpadów poflotacyjnych. W artykule przedstawiono przesłanki rozwiązań technologicznych oszczędzających zasoby, które w procesie wzbogacania rud tytanowo-cyrkonowych pozwalają na oddzielenie skał ilastych od piasku w obrębie wyrobiska, co pozwala na uzyskanie dodatkowych ilości komponentów tytanowo-cyrkonowych i minerałów towarzyszących dla budownictwa oraz na zmniejszenie powierzchni gruntów, wymaganej pod lokalizację składowisk odpadów poflotacyjnych.

Słowa kluczowe: *górnictwo odkrywkowe, złoża tytanu i cyrkonu, technologia górnicza, wzbogacanie rudy, minerały towarzyszące*