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# THE BELT CONVEYOR EFFECTIVENESS AT THE ROCK HAULAGE UNDER FLOODED PIT EXCAVATIONS

**Purpose.** Development of the process scheme of mining-hauling operations at the mining flooded deposits.

**Methodology.** The choice of rational haulage equipment according to the conditions of mining flooded Motronivskyi placer deposit is performed by using the analytical method of research. The graphic-analytical method of research was used in developing the recommended technological schemes of mining-hauling operations using conveyor haulage. For substantiation of technological schemes parameters of overburden transportation, the method of technical and analytical analysis was used.

**Findings.** The world experience in the mining titanium deposits is summarized and the main benefits of underwater mining at Motronivskyi placer deposit are highlighted. The analysis of traditional methods and equipment for overburden rocks transportation to this pit condition was carried out and a new design of a belt conveyor with a rope and mining technology is proposed. The basic indexes of economic efficiency of the developed technology are defined: decreasing operating costs while reducing transportation distance, the net present value (NPV) and internal rate of return (IRR) were estimated.

**Originality.** The obtained research results of determining the impact of changing parameters and equipment in technological mining scheme of Motronivskyi watered alluvial placer deposit using the proposed systems of continuous mining for the overburden remove on the net present value of the project allowed determining the Internal rate of return and payback period.

**Practical value.** Technological solutions for the introduction the connecting conveyor with a rope in the pit field centre in the technological scheme of transporting overburden rocks are justified. The use of floating support on the pontoon allows stabilizing the conveyor belt in a surface part of the deposit. Maintenance of the conveyor elements is significantly simplified and facilitated improving, as a result, work safety and its efficiency.

**Keywords:** *open-cast mine, titanium deposits, flooded deposit, overburden, haulage, conveyor belt, rope*

**Introduction.** Ukraine has significant reserves of titanium ores concentrated in indigenous and placer deposits. To date, placer deposits are placed close to the surface and require relatively little investment in preparatory work for industrial operation. In the near future, the development of the Motronivsko-Annivskyi placer deposit (MAP) of titanium-zirconium ores will begin. The mineral on this deposit is presented by fine-grained clay sand-quicksand with low water loss, which does not allow the use of known methods of dewatering.

Malyshevske titanium-zirconium deposit, located in the Verkhniodniprovskyi district of the Dnipropetrovsk region at a distance of 10 km from the city of Vilnohirsk, has been in operation since 1961 in places where the ore is confined to the Sarmatian formations lying above the groundwater level.

The operating conditions of the MAP differ in the location of the ore body below the groundwater level, which significantly distinguishes the deposit development technology from worked out or exploited open-cast mines. As a result of additional research carried out at the stage of mining and capital works in open-cast mine, it was established that the water-saturated Sarmatian and Poltava sands are quicksands. The location and movement of heavy mining equipment on the water-saturated sands surface is almost impossible, and drainage of the quarry with filtration wells or open drainage ditches is also problematic. That is why it is necessary to use a combined mining deposit system, which includes the overburden stripping with bucket wheel excavating continuous-action complexes, while ore mining should be conducted using a hydromechanization method.

**Analysis of the previous research.** Based on the research studies [1], the main advantages of using underwater mining ore were identified. This method avoids the need for draining the pit by constructing dewatering wells. In accordance with the developed banking feasibility study by the engineering company "Vatenfal" (Germany), the capital costs for the construction of a well system for drainage at the open-cast mine dewatering would be 10.5 million Euros. Also, there is no need to build temporary dams in gullies to intercept and transfer surface waters, followed by the transfer of dams when the mining front reaches them out. However, the results of the work include the use of a conveyor system with a total length of up to 4 km. This huge distance of haulage needs expensive investment.

In work [2] considerable attention is paid to the reconstruction of specific substructures of high-performance continuous machines in conjunction with conveyor transport, but the results of the work do not allow increasing the production efficiency in the conditions of the Motronivskyi open-cast mine development, since they do not provide for a reduction in the transportation length of rocks.

The authors of [3] considered the tasks of strategic planning and operation of a pit taking into account distribution points of the belt conveyor system, as this has a direct impact on the enterprise development. In this research work, the model for the optimal location of distribution points in pits is formulated on the basis of minimizing the cost of transportation during the entire production life of the enterprise. The disadvantage of the work is that the program considers possible distribution points only on the surface of the work sites, and does not imply the use of new types of conveyors that allow the transportation of the rock through above the watered excavation of the pit.

The research carried out in work [4] allows performing mathematical modeling of parameters and design of belt conveyors depending on the conditions of its use. However, the work does not cover the possibility of using conveyors in the watered field conditions at the surface mining deposits.

Thus, the performed studies confirm that underwater mining ore at the Motronivsko-Annivskyi placer deposit is the most rational, but there is a lack of scientific and technical developments in justifying effective solutions for the overburden replacement by continuous type of haulage.

**Unsolved aspects of the problem.** The analysis of research and design works in the field of the choice of efficient haulage equipment at the development of watered fields has shown that the application of known solutions without a detailed justification for the use of conveyor haulage is impossible. This is due to the fact that when using underwater mining ore, the movement of overburden rocks by road on the surface of water-saturated sands is impossible according to safety procedures.

In this regard, there is a need to justify the use of conveyor transport of a new generation for the overburden haulage, taking into account the hydromechanical conditions of the Motronivsko-Annivskyi watered placer deposit.

**Objectives of the article.** To substantiate the technological solutions for the introduction of a new generation of conveyor haulage in the technological scheme for overburden transportation, which includes a connecting conveyor with a rope conveyor flight in the central site of the pit as well as to provide for the use of a floating support on the pontoon and a cable railway, which greatly simplifies and facilitates the maintenance of the conveyor elements.

To determine the impact of changing the parameters and equipment of the mining technological scheme for the watered Motronivskyi placer deposit with the use of the continuous operation complexes proposed for the development of overburden rocks at the mining watered deposits to the net present value of the project, the internal rate of return and the payback period of investments.

**Presentation of the main research.** The most common scheme for the development of placer deposits is a scheme using bucket wheel complexes. Surface mining is developed by a bucket wheel excavator and through the system of belt conveyors is placed in internal waste dumps by a spreader. Ore excavation is carried out by a dragline, which is placed on the roof of the ore bench and loaded ore in the dump trucks, which deliver it to the point of blurring. After the wash-out the ore sand is transported to the processing plant by the hydraulic transport. In the case of the development of a flooded placer deposit, this technology is not feasible.

The project plan for the development of the Motronivskyi placer site of the Malyshevske titanium-zirconium deposit provides for the transportation of rocks by belt conveyors with a rigid post with the pre-installation of belt conveyor links from several units located on stripping faces and on the non-working side of the pit.

After rock excavation from the massif by the bucket wheel excavators, it is loaded onto the face bench conveyor. Transportation of overburden on the non-working side of the pit is carried out by connecting conveyors, which move overburden rock by reloading station to the dump conveyor. It works in conjunction with a spreader directly on the forward overburden bench. On the second overburden bench, an interstage loader is used, with the backfilling of overburden to the in-pit dump (Fig. 1).

The disadvantage of the proposed technological scheme is the considerable distance of overburden rocks transportation from the pit face of the bucket wheel excavator to the dump because of the location of the connecting conveyors on the non-working pit side. As a result, excessive power consumption, increased wear of the belt and rollers, and an increase in the ore production cost occur.

The solution to the problem of reducing the length of overburden haulage with the use of a continuous equipment complex is possible due to the direction of cargo flows from slaughter to the internal dump for the shortest distance. However, a significant complexity of this solution is the technological justification for using a belt conveyor, part of which will be located above the watered space of the working trench.

Based on the analysis and synthesis of possible technical solutions, the authors propose a technological scheme, shown in Fig. 2, using a conveyor system with a rope flight in the central part of the Motronivskyi watered deposit.

The use of this flight in the middle of the pit makes it possible to arrange the supporting structures of the belt conveyor over the watered spaces of the working trench. In addition, the floating base of the ship, which is attached to the base of the watered trench by anchors, can be moved taking into account the location of the mining and dumping equipment thereby reducing the transportation distance of the rock mass from the overburden to the in-pit dumps.

Technological scheme for transportation of overburden rock, while developing flooded placer deposits, is implemented in the following sequence. Previously, at the level of the lower un-watered overburden, the supports are installed by plugging them into the soil to a depth that guarantees stability from moving in any direction. After that, they place ropes with the upper and

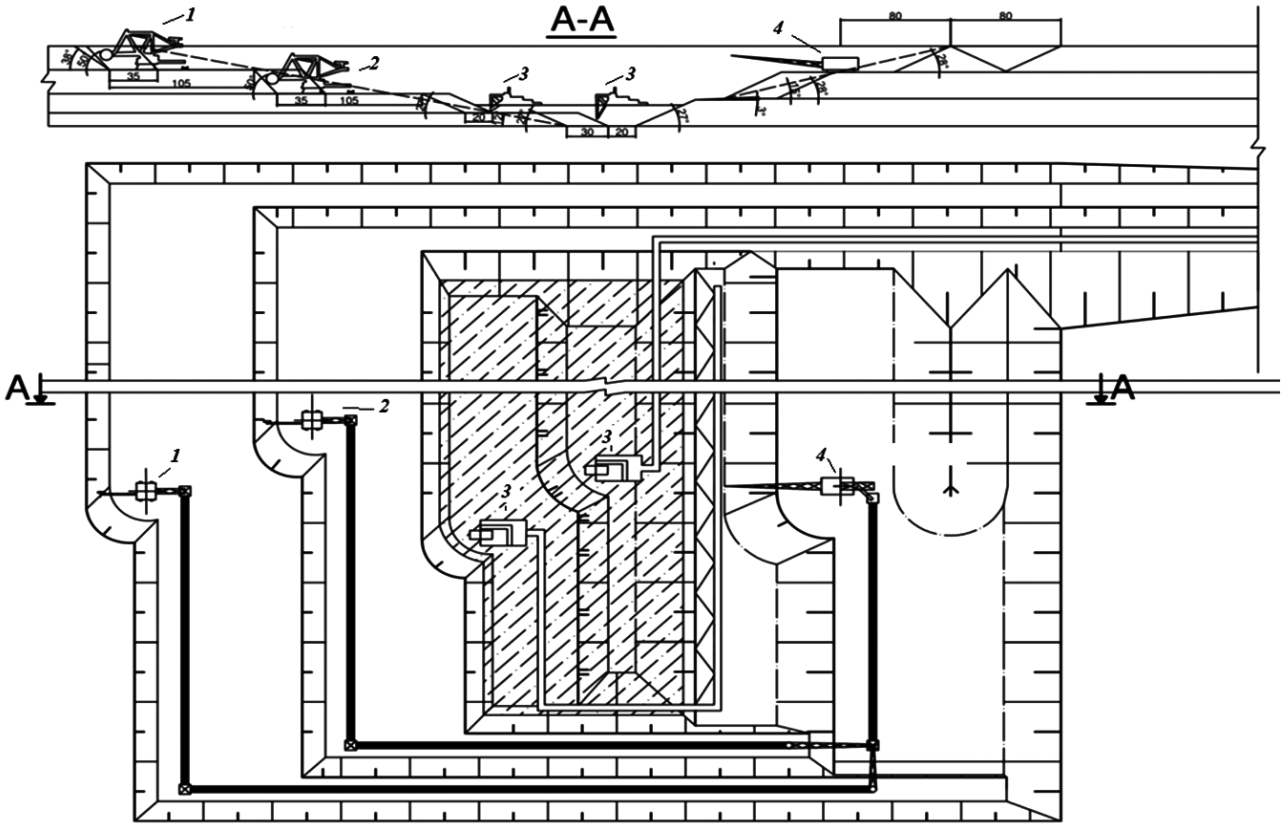



*Fig. 1. The basic technological scheme of mining operations:*
*1 and 2 – excavator ER-KR5600; 3 – dredger SRF; 4 – spreader KB-ZA5600*

lower lines of the tape with the possibility of moving along the mining operations front.

Then, with the help of caterpillar propellers (head and tail), ropes are tightened and oriented in space, to which the roller supports of the working and idle lines of the tape are fixed. After completing the preparatory works install the tape. At the same time, the development of the lower flooded horizons is started by dredges that transport pulp through the pulp pipeline – the first into the dump, the second – to the concentrating mill.

At this mining stage of deposit development, a floating support is installed and fixed by ropes and anchors to the bottom of flooded working trench. The above-water part of the conveyor is equipped with additional rope contours of the telpherage line: carrier cable and traction cable, to the latter, cabs and the drive station are joined with a friction pulley [5]. The telpherage line purpose is to ensure the maintenance of the belt conveyor during the entire pit operation period.

The overburden rock from the second bench mined out by bucket wheel excavator *1* through the hopper is delivered to the belt elevator from it through the hopper to the face conveyor, located on the second overburden bench. Then the conveyor haulages overburden rocks to the belt elevator between benches.

Bulk cargo from an inter bench loader by a dump conveyor is delivered to the spreader *3*, which forms a dump. The overburden rock from the bucket wheel excavator on the second bench is immersed directly onto the face conveyor *7* and then runs along the same path.

As the overburden rock mass is worked out by bucket wheel excavators and dredgers the dump section of the pit is formed. The conveyor is moved along the front of mining operations with the help of a caterpillar mover. In this case, the released supports from the dump are transferred along the front of the mining operations and installed on the ore bench face. The floating support is also moved and fixed in a new place by anchors.

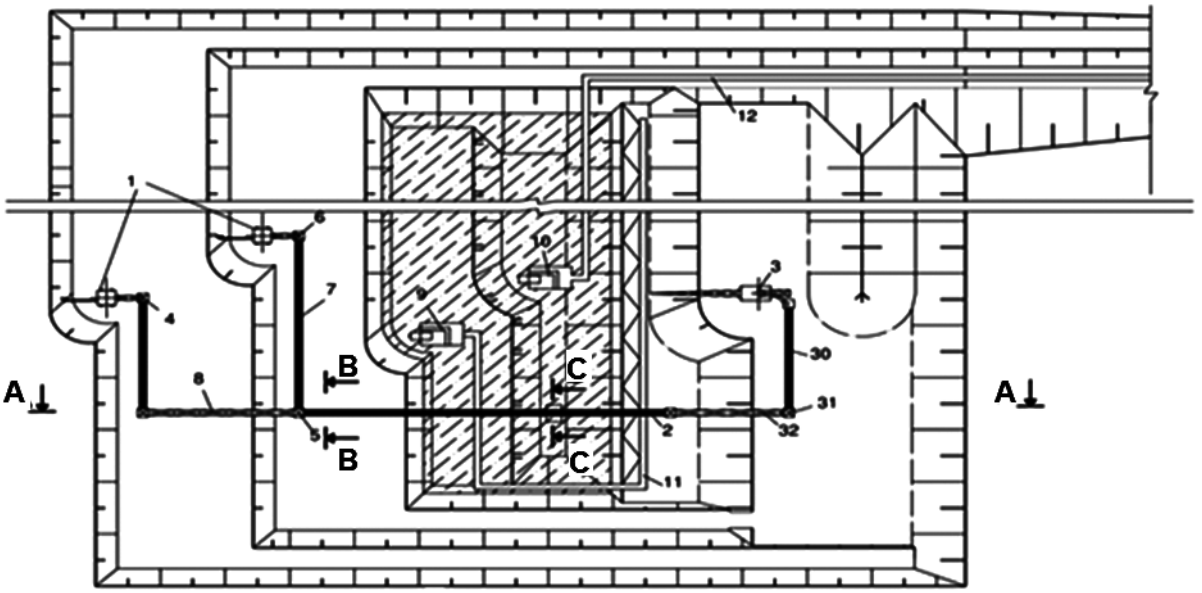
As can be seen from Fig. 2, the bunkers *4, 5, 6, 31* provide ordered loading of conveyors *2, 7, 8, 30* with overburden rock.

Thus, while solving the first task, possible technological solutions were found to reduce the distance of transportation of overburden to the internal dump with the use of continuous technology, as well as the location of the part of the belt conveyor over the watered mine workings.

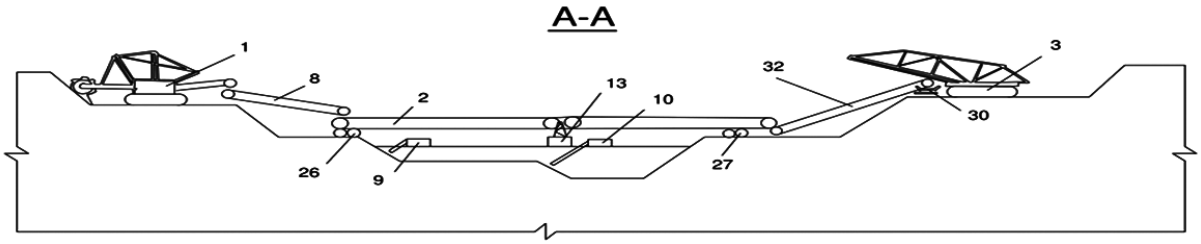
However, the use of new technological solutions, which involve the modification of transport equipment, is associated with an increase in capital costs. This requires a detailed feasibility study to justify the feasibility of replacing equipment.

The use of a new transport scheme for overburden under the conditions of the development of the Motronivskyi ilmenite ores deposit can be effective only if the capital expenditures for new equipment allow reducing further operational costs substantially during the operation of the enterprise.

While solving the second task of the research, which was to determine the effect of changing the parameters and equipment of the technological scheme for development of




*a*

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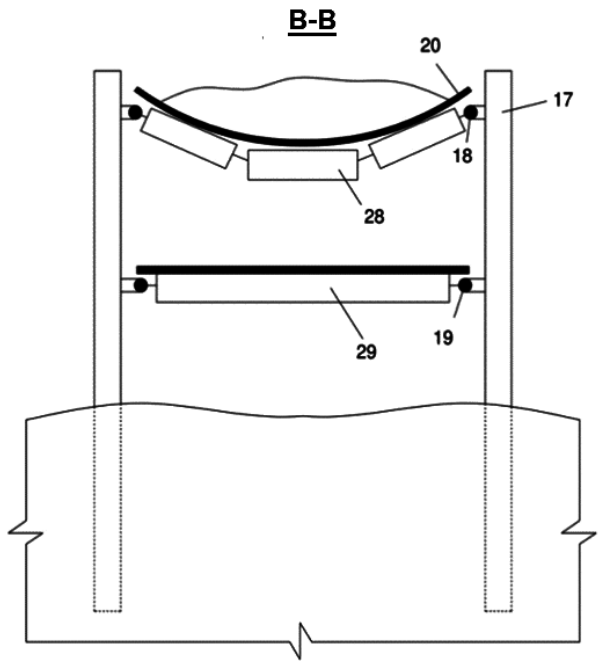


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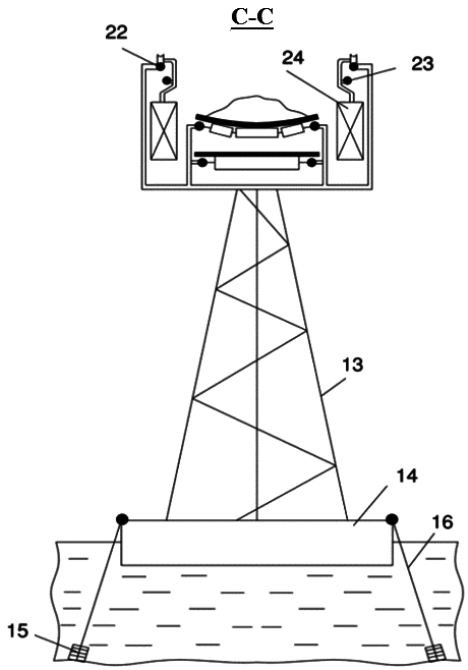


*d*

*Fig. 2. Recommended technological scheme of mining operations:*

*a – plan; b – cross section; c – conveyer support section; d – floating support section; 1 – face bucket wheel excavator; 2 – belt conveyor; 3 – spreader; 4, 5, 6, 31 – bunkers; 7 – face conveyor; 8 and 32 – belt elevator between benches; 9 and 10 – dredges; 11 and 12 – slurry pipelines; 13 – floating support; 14 – platform; 15 – anchors; 16 – ropes; 17 – supports; 18 and 19 – ropes; 20 – tapes; 22 – carrying rope; 23 – traction cable; 24 – cabin; 26 – the main caterpillar mover; 27 – tailed caterpillar mover; 28 and 29 – roller supports of the working and idle belt lines; 30 – dump conveyor*

the Motronivskyi open-cast mine with the use of the complexes of continuous-action proposed for mining operation at the excavation of overburden rocks of flooded placer deposits, the net present value of the project, the internal rate of return and the payback period of capital investments were determined. The economic efficiency calculations for the proposed technological mining scheme are performed.

While conducting the research studies the economy of operating costs was defined with a reduction in the transportation distance from 2000 to 1000 meters due to the use of conveyor transport of a new generation at the haulage of overburden during the watered field development.

The economy of operating costs, which is achieved by reducing the length of the conveyor, is formed as a result of a decrease in electricity consumption, a reduction in the number of roller bearings of the working and idle branches of the belt, a reduction in the length of the conveyor belt, and in the scope of work for the maintenance and repair of the conveyor.

Preliminary calculations made it possible to determine the operating costs for mining operations and haulage of overburden rocks to the internal dump. These indicators will change with the introduction of a new technological scheme for transportation of overburden with a conveyor using a floating platform.

The results obtained during the implementation of the studies coincide with the indices according to the working project of mining the Motronivskyi placer deposit, the projected prime cost of extracting and transporting overburden rocks by the bucket wheel complex (for the conditions of the Motronivskyi placer deposit) $C$ is 34.5 UAH/m$^3$. With the planned production output of the bucket wheel excavator for overburden of 9.0 million m$^3$ per year, the savings in operating costs will be, million UAH per year

$$C_{O.S} = Q_k \cdot C_H \cdot \Delta l_{TR}^{AV} = 9 \cdot 10^6 \cdot 17.25 \cdot 1.0 = 155.25,$$

where $\Delta l_{TR}^{AV}$ is the length of overburden rocks transportation according to the new technological scheme, km; $C_H$ is the haulage cost for replacement of 1 m$^3$ of stripping rocks per 1 km, UAH/ m$^3$ · km

$$C_{TP} = \frac{C}{l_{TR}^{AV}} = \frac{34.5}{2.0} = 17.25,$$

where $l_{TR}^{AV}$ is the average distance of overburden transportation for the bucket wheel complex at mining the Motronivskyi open cast mine with the existent technological scheme, km.

During the research, the investment attractiveness of the proposed technological mining scheme for the development of watered fields was also calculated. Currently, the most common method is to determine the economic efficiency of investment projects in terms of improving the production performance of the enterprise, based on indicators that make it possible to assess the feasibility of capital investments more systematically. These indicators are net present value – NPV and internal rate of return – IRR.

The net present value is an indicator characterizing the overall absolute result of an investment project – NPV. It is calculated as the sum of the annual savings of current expenses, with the exception of expenditures indicated in the current year, UAH

$$NPV = \sum_{t=1}^{T} \frac{\left(P_t - B_{ut} - B_{et}\right)}{\left(1+r\right)^t},$$

where $P_t$ is the amount of savings in current costs during the stage of work at the introduction of new technologies for the $t$ year, thousand UAH; $B_{ut}$ is the amount of capital investments at the stage of works in the $t$ year, thousand UAH; $B_{et}$ is the amount of additional running costs associated with the introduction of the mining work stage in the $t$ year, thousand UAH; $r$ is the inflation index in the $t$ year, relative unit.

To calculate the net present value of an investment project, it is necessary to establish the amount of current cost savings from the introduction of new technological schemes for mining the placer deposit. Currently, as the basic technological scheme at the Motronivskyi MPP a technological scheme is used in which advanced benches are worked by hydraulic excavators, the overburden bench over ore bed – by the dragline, and the ore – by the dredger.

With the introduction of new technological schemes, the annual savings $P_t$ from the implementation will be calculated accordingly, as the difference between operating costs of the basic and proposed schemes, where bucket wheel complexes of continuous operation are used as the main overburden equipment.

The amount of capital investments at the $B_{ut}$ stage is calculated in accordance with the need to purchase mining equipment for each of the technological schemes that are being considered. The main difference between the calculations is the need to replace equipment with diesel engines, which include hydraulic excavators and dump trucks, every seven years.

However, technological schemes in which draglines or continuous-action complexes with bucket wheel excavators are used as retrieving and handling equipment will have capital costs for the 14$^{th}$ and 30$^{th}$ years of pit exploitation, respectively. This is due to the long service life of machines with electric motors declared by the manufacturing plants. The calculation of the capital investments performance was carried out for a period of fourteen years from 2017 to 2030.

The internal rate of return (IRR) of the proposed technology is determined at a discount rate level at which the net present value of the project for the period of its implementation will be zero

$$IRR = \sum_{t=1}^{T} \frac{\left(P_t - B_{ut} - B_{et}\right)}{\left(1+r\right)^t} = 0.$$

The internal rate of return is the one below which the introduction of this technology gives a negative overall profit. The value calculated for this project – $IRR$ should be compared with the discount rate $R_{cr}$, or the inflation rate $r_k$, or the discount rate $r$. The value of $IRR$ is determined by the method of selection and verification of successive values $r$ ($r > IRR$).

The calculation of capital investment performance was carried out for a fourteen-year period from 2017 to 2030 in accordance with the initial data. The most efficient to implement is a scheme with a continuous operation on two overburden benches with a height of 24 m. In the second place is a scheme with the same overburden equipment, with the height of the ledges being 20 m. The worse is the scheme with draglines for the development of advanced benches with a total capacity of 37 m with the loading of overburden rocks in the truck haulage.

However, according to the results of the research, which consisted in comparing the efficiency indicators of capital investments when choosing an effective technological scheme for the development of the Motronivskyi placer deposit, it was found that the most attractive for use is the technological scheme with a continuous complex, which develops an advanced overburden with a capacity of 30 m. After this the overburden is transported by belt conveyors to the internal dump. According to this scheme, the second overburden bench with a height of 7 m is worked out by hydraulic excavators. The above-ore overburden 16 m bench is worked out by a dredger with a hydraulic monitor, the minerals are developed by a dredger, and then transported to a concentrating mill.

The conducted research studies have shown necessity and validity of application of the proposed estimation principles for establishment of economic efficiency of technological decisions at surface mining of titanium-zirconium placer deposits. Evaluation of the investment attractiveness of the technological development schemes introduction, based on the calculation of economic indicators such as: net present value, payback period, income-expenditure ratio, internal rate of return, profitability ratio, capital productivity, allows determining the most efficient technological scheme of mining deposits in advance.

**Conclusions and recommendations for further research.** The conducted research studies made it possible to establish that the introduction of a connecting conveyor with a cable car in the central part of the pit into the technological scheme of overburden transportation while developing flooded placer deposits allows reducing the transportation distance of overburden. It also decreases the amount of equipment and its weight without reducing the production capacity of the pit, which will improve energy efficiency, operational reliability and economy at the surface mining of watered placer deposits.

The use of floating support on the pontoon allows ensuring the stabilization of the pipeline route in the above-water part of the field and, thereby, increasing the safety and reliability of the complex operation.

The introduction of a cable railway into the construction of a conveyor installation makes it much easier to maintain the conveyor elements, which leads to fewer injuries and higher labor productivity.

When implementing the technological scheme with the continuous-action complexes proposed for developing overburden rocks of flooded placer deposits, the annual operating costs savings will amount up to 155.25 million UAH, while the net present value will amount to 1206.9 million UAH, with an internal rate of return of 20.3 % and a payback period of investments – 8 years.

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## Ефективність використання конвеєрів при транспортуванні порід над обводненими виробками кар'єрів

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**Мета.** Розробка технологічної схеми гірничотранспортних робіт в умовах обводнених родовищ.

**Методика.** Вибір раціонального транспортного устаткування для умов розробки обводненого Мотронівського розсипу виконано шляхом використання аналітичного методу досліджень. Графоаналітичний метод досліджень використовувався при розробці технологічних схем гірничотранспортних робіт із застосуванням конвеєрного транспорту. При обґрунтуванні параметрів технологічної схеми транспортування розкривних порід застосовувався метод техніко-аналітичного аналізу.

**Результати.** Узагальнено світовий досвід розробки титанових родовищ і виділені основні переваги підводного видобутку руди на Мотронівському розсипі. Проведено аналіз традиційних схем та обладнання транспортування порід розкриву для умов таких родовищ і запропонована нова конструкція стрічкового конвеєра з канатним поставом і технологія гірничих робіт з його використанням. Визначені основні показники економічної ефективності розробленої технології: зниження експлуатаційних витрат при зменшенні відстані транспортування, чиста наведена вартість (NPV) і внутрішня норма прибутковості (IRR).

**Наукова новизна.** Отримані результати досліджень зі встановлення впливу зміни параметрів і обладнання технологічної схеми відпрацювання Мотронівського розсипу із застосуванням запропонованих у роботі комплексів безперервної дії для розробки порід розкриву обводнених розсипних родовищ на чисту наведену вартість проекту, що дозволило визначити внутрішню норму прибутковості й термін окупності капіталовкладень.

**Практична значимість.** Обґрунтовані технологічні рішення щодо введення до технологічної схеми транспортування розкривних порід з'єднувального конвеєра з канатним поставом у центральній частині кар'єрного поля. Застосування плавучої опори на понтоні дозволяє забезпечити стабілізацію траси конвеєра у надводній частині родовища. Можливість застосування підвісної канатної дороги суттєво спрощує й полегшує обслуговування елементів конвеєра, що дозволяє підвищити безпеку праці та її економічність.

**Ключові слова:** *кар'єр, родовище титану, обводнене родовище, породи розкриву, транспортування, конвеєр, канат*

## Эффективность применения конвейеров при транспортировании пород над обводненными выработками карьеров

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**Цель.** Разработка технологической схемы горнотранспортных работ в условиях обводненных месторождений.

**Методика.** Выбор рационального транспортного оборудования для условий разработки обводненных россыпных месторождений выполнен путем использования аналитического метода исследований. Графоаналитический метод исследования использовался при разработке рекомендуемой технологической схемы горнотранспортных работ с применением конвейерного транспорта. При обосновании параметров технологической схемы транспортировки вскрышных пород применялся метод технико-аналитического анализа.

**Результаты.** Обобщен мировой опыт разработки титановых месторождений и выделены основные преимущества подводной добычи руды на Мотроновской россыпи. Проведен анализ традиционных схем и средств транспортирования вскрышных пород для условий таких месторождений, предложена новая конструкция ленточного конвейера с канатным ставом и технология горных работ с его использованием. Определены основные показатели экономической эффективности разработанной технологии: снижение эксплуатационных расходов при уменьшении расстояния транспортирования, чистая приведенная стоимость (NPV) и внутренняя норма доходности (IRR).

**Научная новизна.** Полученные результаты исследований по определению влияния изменения параметров и оборудования технологической схемы отработки Мотроновской россыпи с применением предложенных в работе комплексов непрерывного действия для разработки пород вскрыши обводненных россыпных месторождений, на чистую приведенную стоимость проекта, позволили определить внутреннюю норму доходности и срок окупаемости капиталовложений.

**Практическая значимость.** Обоснованы технологические решения по введению в технологическую схему транспортирования вскрышных пород соединительного конвейера с канатной установкой в центральной части карьерного поля. Применение плавучей опоры на понтоне позволяет обеспечить стабилизацию трассы конвейера в надводной части месторождения; возможность применения подвесной канатной дороги. Существенно упрощается и облегчается обслуживание элементов конвейера, за счет чего повышается безопасность работы и ее экономичность.

**Ключевые слова:** *карьер, месторождения титана, обводненное месторождение, вскрышные породы, транспортировка, конвейер, канат*

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