KEY TRENDS OF INTEGRATED INNOVATION-DRIVEN SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT OF MINING REGIONS

MULTI-AUTHORED MONOGRAPH

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The monograph considers potential technological development of ore mining and processing industries through updating mining machines and technologies

The book is intended for a broad mining audience of scholars, practitioners, postgraduates and students.

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PREFACE

Multi-authored monograph "Key trends of integrated innovation-driven scientific and technological development of mining regions" edited by Prof. Zinovii MALANCHUK and Prof. Maria LAZAR.

We are happy to present the multi-authored monograph "Key trends of integrated innovation-driven scientific and technological development of mining regions".

The monograph presents findings of research into elaboration of conceptual foundations of the strategy of innovation-driven scientific and technological development of mining regions based on a system approach to using their integrated resource.

Mining enterprises aim to increase the use of potential resources of deposits. In this regard, they need a strategy for mining specific types of mineral resources in various mining regions.

The monograph considers findings of research into the integrated mining of mineral deposits: from geological assessment to extraction and processing of minerals. The state and prospects for using technical, environmental and energy resources of regions are analyzed as well.

The monograph is intended for a wide range of scientists, specialists involved in analyzing development of mining complexes in regions, as well as master's and doctoral students of relevant specialties of higher educational institutions.

Co-editors,
Zinovii MALANCHUK - Professor, DSc. (Engineering), Director Institute of Postgraduate Education, National University of Water and Environmental Engineering, Ukraine
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JUSTIFICATION OF THE EXPEDIENCY OF COMPLEX PROCESSING OF BASALT RAW MATERIALS AT PRJSC "RAFALIV QUARRY"

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Summary

This work is devoted to the study of the feasibility of implementing a research and production site for the extraction of copper concentrate and related metals from basalt mining mass at PrJSC “Rafaliv Quarry”. In particular, issues of description of the technical essence of the project, possible areas of application of the extracted copper concentrate, assessment of the scientific and technical level of the project, technical and organizational conditions of project implementation, assessment of project implementation terms, results of marketing research of the product market, organization of advertising, assessment of entrepreneurial risks during implementation are considered.

Since complex processing of metal-containing basalt raw materials has not been carried out in Ukraine, and the presence of native copper in it is unique, there is a need to analyse the material composition and technological properties of each of the rocks in the ore preparation processes.

As a result of the study, it was established that the main carriers of copper mineralization are basalts, basalt tuffs and lava-clastic breccias with a very uneven content of copper in rocks of different petrographic composition. The copper content in basalts, tuffs and lava-classical breccias is up to 5%.

The developed approaches will make it possible to implement rational processing technologies for the extraction of copper concentrate and related metals from basalt mining mass at the experimental site of PrJSC "Rafaliv Quarry".

Introduction

In the Rivne region (Ukraine), there are more than 600 mineral deposits, which are represented by 18 types. At the moment, 242 deposits are registered by the state balance sheet of mineral reserves, 84 of them have been developed by industry and 59 mining enterprises operate on their basis [1-3].

The program for the development and industrial development of mineral and raw materials resources of the Rivne region for the period until 2030 is aimed at the development of priority areas of geological research in order to provide the economy of the region and Ukraine with those types of mineral raw materials that are found on the territory of the Rivne region.

State and regional priorities include program projects, which provide for the continuation of geological prospecting for copper and diamonds.

There are also prospects for the discovery of industrial native copper deposits within the Rafaliv copper ore cluster and positive signs for the discovery of native diamond deposits in the northern regions.

Ukraine's projected needs for 2022-2025 will amount to more than 170,000 tons. Currently, Ukraine has no explored reserves of copper ores, but the prospects for discovering them are quite significant.

Prospects for extraction of copper from the deposits of the Western region of Ukraine

The search for native copper deposits is conducted by the Rivne Geological Expedition of the Northern State Regional Enterprise "Pivnichgeologiya" in four areas: Tursko-Lugov, Kuhotsko-Volyn in the territory of the Volyn region, and Mid and Rafaliv in the Rivne region.

Exploratory drilling was conducted to test basalt rocks for copper and potentially possible precious metal mineralization within the Rafaliv ore complex. A total of 56 wells with a depth of 4 to 178 m, with a total volume of 5,493 linear meters, were drilled. 746 samples were selected for determination of copper content, 35 samples for determination of physical properties of rocks, 44 samples for conducting other studies [3, 4].

As a result of the performed works, a clear timeliness of copper mineralization to lava breccias and unaltered basalts at the bottom of lava basalt flows was established.

The range of copper mineralization reaches several meters with copper content from 0,1 to 0,76%.

Native copper was also found in the lava breccias of the lower basalt flow in the southwestern part of the Rafaliv quarry on an area of 2,5 hectares.

The Rafaliv ore node is located in the western part of the Rivne region. The Kyiv-Warsaw railway and highway pass through its northern part.

The prospect of native copper mineralization is confirmed by the large volumes and wide area development of ore-bearing rocks, the presence of several ore horizons with established industrially significant copper contents in ores, the native nature of mineralization, manifestations of accompanying mineralization, the possibility of complex use of ore-bearing rocks, favorable mining and technical conditions for the location of ore horizons, ecological safety of ore processing [5-7].

Copper mineralization is represented mainly by native copper in the form of finely fine-grained, lamellar dendrites and nuggets weighing up to 700 g. The distribution of copper in the rock is uneven. It is concentrated in the cement of lava breccias, in the spatial association and nests of the analcime mineral. The copper content varies from 0,05 to 5,24%.

The performed works revealed two zones of mineralized lava breccias with a thickness of up to 1,6 m, which extend in the meridional direction for a distance of 1,0 and 1,5 km, respectively, with a width of 200-400 m.

Precious metal mineralization is developed in copper-bearing lava breccias and minor volumes: silver 5,4 g/t, gold up to 0,007 g/t.

The State Geological Service of Ukraine developed and approved the "Program for the Search and Exploration of Native Copper Deposits within the Rafaliv Ore Node", which provided for the completion of searches within the Rafaliv Square and conducting prospecting and evaluation works in its most promising areas [1, 5].

After completing the search in the South Rafaliv area. Technical and economic considerations were made according to 8 options: commercial products (copper concentrate and copper metal), with an on-board content of copper in the ore of 0,1; 0,2; 0,3; 0,4% using 75% enrichment tails. Positive profitability is achieved with an on-board content of 0,3; 0,4%.

According to the results of the geological and economic assessment, a site with an area of 23,6 km^2 with promising resources of the P_2 category in the amount of 761 thousand tons of copper was allocated, on which works of the exploration and evaluation stage are being performed [2,7].

The main tasks of this direction are:

carrying out prospecting and evaluation works at the Rafaliv ore node for the preparation of prospective ore deposits (deposits) for exploration;

exploration of one of the best discovered deposits and its preparation for industrial development with estimated reserves of 1 million tons of copper.

Justification of the implementation of the research and production site for the extraction of copper concentrate and related metals from basalt mining mass

Brief description of the technical essence of the project

Currently, the area of the Volyn copper ore district has been studied by geological surveys and deep geological mapping. Geological mapping was accompanied by geophysical research: gravity, magnetic, electrical exploration, profile seismic exploration.

According to the State Department of Ecology and Natural Resources, there are several hundred deposits of various minerals in the Rivne region. From an economic point of view, copper deposits are the most interesting. According to preliminary calculations, the resources of this metal in individual deposits near Rafaliv can reach from 100 to 600 thousand tons in terms of pure copper. Currently, two search areas have been allocated on the area of the ore node measuring 40×50 km - Midsk and Rafaliv.

According to the indicators of the assessment of the native copper deposit of the Rafaliv site on the area of ore horizons of 4,85 km^2, the forecast resources of copper are 1.4 million tons, gold - 24,0 c.u., silver - 600 c.u., platinoids - 20,0 c.u. Estimated resources of multicomponent ore - 20,4 million tons, copper - 1,326 million tons. The mining life span is 13,6 years.

It is proposed to organize a research and production site for the mining and extraction of native copper and related materials in the conditions of the active basalt quarry for the purpose of further sale on the market of Ukraine. It is also proposed to work out an effective processing technology for the development of a technical task for the creation of a larger-scale enterprise.

Currently, the work has established the regularities of extraction of copper nuggets with different methods of crushing and classification of basalt and tuff. The regularity of the formation of the core of valuable components (containing 90-95% of minerals) during hydraulic washing and hydraulic transportation of the mining mass was previously established. On this basis, the technology of finding the core of minerals and its selective extraction was developed.

The end product of production is native copper or a concentrate (since there are joints of copper with host rocks).

The second product of copper enrichment is pure basalt or tuff. Currently, basalt is used only as a building material in the form of crushed stone of various fractions. But factories in Ukraine have mastered the petrological technology of making ecologically clean heat-insulating wool from molten basalt, which is widely used in construction.

After enrichment and extraction of useful components, tuff is a ready-made material for the manufacture of water filters, it is used as a feed supplement for livestock and poultry, and also as an ameliorant for sod-podzolic soils. Tuff flour is suitable for the production of building ceramics, high-quality bricks and expanded clay.

Possible areas of application of the product

The use of copper is quite diverse and covers all branches of mechanical engineering, instrument building, electrical engineering industry, transport (trolley of trains, trolleybuses, trams), radio-electronic industry, etc. Considering the shortage of copper in Ukraine, the realization of the product does not cause difficulties. The use of basalts for construction and the chemical industry will continue in the established order with the search for new areas of application.

The use of tuffs has not been mastered by various areas of the national economy, therefore, first of all, it is necessary to carry out a set of technological studies of their properties and develop technical conditions and recommendations for expanding their use. But even now, tuff, following the example of the "Tashki" deposit in the Slavut District, is an important raw material component for the fodder base.

Evaluation of the scientific and technical level of the project

The shortage of copper in Ukraine is quite noticeable, so the search for this important non-ferrous metal has been intensified. According to the state program "Copper of Ukraine", scientific research in this direction began to be conducted more actively. Only the scientists and specialists of the implementing organizations of this project published monographs, dozens of articles in special publications, trained doctors and candidates of sciences, created more than a dozen inventions on specific problems of technology and equipment. For several years, research and the search for technological solutions for industry have been conducted with the participation of academic science.

The results of this work made it possible to draw up a regional program of comprehensive development of Volyn basalts for the extraction of native copper and other valuable metals.

Technical and organizational conditions of project implementation

Implementation of this project can be submitted in 3 stages.

1st stage - research and production area. Pre-industrial preparation of technology and equipment for copper mining. Production will be organized at a basalt quarry in the form of an experimental site (at the first stage). On this site, the most effective equipment will be selected for the implementation of the technological scheme of the enterprise, semi-industrial research will be conducted on the extraction of copper or its industrial product, the equipment of the premises for the staff of the work stations, storage areas and premises for all types of products, communication and transport networks will be allocated.

The 2nd stage is the expansion of the city's enterprise and the mastering of the fine technology of extraction of associated metals, which are in the processed mining mass (gold, silver, platinum, etc.). Volcanic tuff contains most of iron, titanium, manganese, zeolites, smectites.

The development of the technology of their extraction can be carried out together with the main process, but the development of a new technology increases the range of innovative products and increases the profitability of the enterprise.

The 3rd stage is the comprehensive processing of basalt raw materials using a waste-free technology that is environmentally friendly.

This stage develops mainly due to the increase in the volume of the enterprise. Its implementation is planned for the second five-year period of this project.

According to the project, the creation of a research and production site is planned on the territory of the Rafaliv basalt quarry (Ivanchi village, Volodymyretsk district, Rivne region), which produces basalt for the needs of the construction industry. Associated materials in the basalt deposit, such as tuff and lava breccia, are only partially used.

On the territory of the quarry in the safe zone there is a one-story building, which is currently not in use and, upon agreement with the quarry management, can be rented out. It requires repairs, the cost of which is provided for in the estimate of this project.

The total area of the territory leased for the plot is 820 m^2 (20,5×40 m), including the production premises of 220 m^2. It consists of four separate rooms with areas of 25 m^2, 33 m^2, 133 m^2 and 25 m^2, respectively. In these rooms, it is planned to place the equipment of the site.

The territory of the site is located 600 m from the crushing and sorting area of the quarry crushing factory and one kilometre from the quarry management house.

There are no communications (water, heat, electricity) in the house. It is necessary to install a power transformer and connect a power transmission line.

The site requires a fence, improvement of the territory, and heating of the premises in the cold season. There are access roads to it both from the side of the quarry and from the side of quarry management.

Assessment of project implementation terms

The launch of the research and production site is planned to be carried out within 4 months. During this period, it is planned to perform the following works:

- purchase of the main site equipment - 3 months;
- construction and installation work on the site - 2 months;
- to carry out the development of the technical task, the development of the site project - 1 month.

It is planned to carry out scientific and research works, as well as works related to obtaining technical conditions in permitting authorities (State Inspection, SES, ecology, energy inspection, etc.) and licenses within 18 months.

The results of marketing research of the product market

The offered products are: native copper (main product), crushed basalt, tuff (by-products). Subsequently, after improving the technology of enrichment of the extracted mining mass and establishing the amount of associated metals that the technology will allow to extract, its products will additionally be valuable metals. The product will be sold directly by the customer and with the help of dealers.

Product market analysis. A significant need for copper in Ukraine is met by imports (currently about 250,000 tons per year). Copper is not mined in Ukraine - only geological exploration work is being carried out, which has already shown that its reserves in the bowels of the country make it possible to conduct pre-industrial preparation.

There are a small number of native copper deposits in the world. Its development was carried out in the past centuries with the appropriate technique and technology, therefore, modern technologies, among other things, take into account the peculiarity of the host rocks and the geology of the deposits, based on new possibilities.

Assessment of business risks during the implementation of the proposal

During the design of the experimental site, project risk assessments were also carried out, which are presented in Table 1.

Advertising organization

For the successful sale of final products, the following advertising measures are planned:

1. Participation in industry exhibitions, scientific and practical conferences and symposiums.

2. Advertising in specialized international periodicals. Publication of scientific and scientific-practical materials on extraction and effective use of the entire range of innovative products. Proposals for the implementation of a new technology of production and use of products.

Table 1

Project risk assessments

Possible risks	Risk level	Level justification
Risks associated with changes in the market		
Market trends	Very low	- market trends are positive both in the short term and in the long term. – positive dynamics of the demand in Ukraine for innovative products according to the project.
Terms of competition	Very low	- the presence of advantages in consumer characteristics and significantly lower cost of innovative project products compared to imported ones. - lack of competitors in the country, as this type of technology is being used for the first time. - presence of significant demand in the domestic market.
Inflationary and devaluation processes	Very low	- most costs at the enterprise are largely independent of exchange rate factors and can be repaid at the expense of the price of final processing products, which practically keeps the level of profitability unchanged.
Risks associated with management		
Lack of personnel	Low	- the developing enterprise has at its disposal experienced and qualified scientific and engineering-technical potential, which ensures a high level of technology. - the labor market in the area of the construction of the research and production site is able to provide the enterprise with the necessary qualified personnel. - the need for specialists of all professions under the project is met by educational institutions of Ukraine.
Risks associated with production		
Production process	Low	- the production program according to the project takes into account the lowest copper content in basalt and tuff deposits, but fluctuations in the content can be tenfold. Therefore, the production process must ensure the planned indicators of native copper extraction at a high technical level.

3. Advertising in periodicals of Ukraine. The natural uniqueness of native copper deposits allows to simplify the technology of its extraction, and the possibility of having chemically pure copper as the final product significantly changes the technology and improves the products of the customer enterprises. This refers to the electrical engineering industry.

4. Creation of your own website on the Internet with constant renewal of its information about the volume of production, examples of wide industrial use of all innovative products, recommendations for their use in non-traditional sectors of the economy and proposals for implementation. And here it will be important to show finished products, examples of their use as documentary tapes at specific enterprises.

Conclusions

According to the results of geological surveying, prospecting and thematic works, four ore nodes were identified in the region: Gornikovsk, Kuhotsko-Volsk, Rafalivsk and Shepetilivsk.

The potential resources of each of them are estimated at 5-7 million tons of copper.

It was established that the main carriers of copper mineralization at PrJSC "Rafaliv Quarry" are basalts, basaltic tuffs and lava-clastic breccias with a very uneven content of copper in rocks of different petrographic composition.

So, for example, if in basalts and tuffs there is native mineralization with a copper content of up to 1% in the ore interval of 1,5-2,0 m, then in lava-classic breccias it varies from 0,04% to 5,0%. It has been established that copper deposits are promising for production and require further study and preparation for experimental and industrial copper mining.

The justification for the use of the work results in the form of the efficiency calculations of the innovative construction project use of the site for complex processing of basalt raw materials in the production cycle of the quarry has been developed.

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RESEARCH OF DEPOSITS, THEIR CHARACTERISTICS AND FEATURES OF AMBER OCCURRENCE IN AMBER-BEARING DEPOSITS OF UKRAINE AND THE WORLD

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Abstract

The paper describes the location of amber deposits in different countries of the world with physico-mechanical and chemical properties.

A potential source of amber production can be exhausted deposits with off-balance reserves, which are man-made deposits, but this requires the development of a technological process.

Due to the imperfection of the existing technologies, losses of minerals in targets and dumps exceed 50%.

Existing technologies for extracting amber from sandy and sandy-clay rocks have a high energy intensity of rock destruction, and segregation requires improvement of technology and equipment to increase the efficiency of the final product extraction process and reduce energy, water and air consumption.

The proposed technological schemes do not provide for an ecological component, the possibility of mining waste reclamation, while their man-made nature requires additional research taking into account various mining and geological characteristics and host rocks and the development of recommendations for technology and equipment taking into account the ecological component.

Introduction

Th main task facing the mining industry is to ensure an increase in the production of minerals due to the increase of production in the most efficient open and underground method based on the wide implementation of progressive technology and mining transport equipment.

The current state of development of mining production in the field of mineral development in the Rivne-Volyn region is characterized by the presence of a significant number of industrially significant amber deposits that are developed and those that are not involved in development due to the impossibility of their exploitation by traditional methods, because they are in difficult mining and geological conditions. Exploitation of such deposits by traditional methods is inefficient and costly.

The hydraulic and hydromechanical method of extraction, which is carried out with the help of hydraulic energy, which is used to destroy amber-bearing rocks and deliver amber to the surface, allows efficient development of amber deposits. Identifying the peculiarities of the location of amber deposits, their characteristics in different countries of the world with the indication of physical, mechanical and chemical properties is undeniably relevant.

The purpose of the research is to identify the features of the location of amber deposits, their characteristics in different countries of the world with the indication of physical, mechanical and chemical properties and proposals for improving technologies and equipment to increase the efficiency of the process of extracting the final product and reducing the consumption of energy, water and air.

The subject of research is deposits, their characteristics and features of amber occurrence in amber-bearing deposits of Ukraine and the world.

The object of research is the amber-bearing areas of the Rivne region.

Scientists dealt with the problems of amber mining: Bulat A.F., Nadutyi V.P., Malanchuk Z.R., Lustyuk M.G., Kravets S.V., Kornienko V.Ya., Romanovskyi O.L., Malanchuk E. .Z., Nikitin V.G., Kirikovich V.D., Kononenko E.A., Sierdobolskyi B.N., Hrystiuk A.O., Krynytska M.V. and other.

Large deposits of amber were discovered in the Volyn, Zhytomyr, and Rivne regions. The most explored is the Klesivske deposit, located in the Sarnensky district of the Rivne region. On the territory of Ukraine, amber is found in Volyn, in the basin of the Pripyat River, in the area of Kyiv and in the Carpathians.

In modern economic conditions, the efficiency of hydraulic mining equipment can be increased by substantiating the rational factors affecting the process of hydromechanized mining and improving the existing technological equipment based on the application of the automatic control system for the hydraulic washing process. However, known extraction technologies do not allow to fully extract amber due to the imperfection and lack of effective technology for the complete extraction of amber from amber-containing deposits.

The complexity and large number of possible technological processes of extraction and the specifics of the operating conditions of deposits indicate that for the study and extraction of minerals there is a need to conduct additional studies of equipment complexes as part of hydromonitors. Increasing the efficiency of such complexes by reducing energy costs while increasing the assortment and improving the quality of products requires scientific substantiation of the parameters of the constituent elements of mining complexes of a new technical level.

The conditions of the accumulation of primary amber placers in the amber-bearing areas of the Rivne region are given based on the research materials of M.V. Krynytska, a senior lecturer of the Department of Geology and Hydrogeology of the NUWEE.

1. Historical and geographical characteristics of the location of amber deposits

The ancient Greeks believed that giving amber as a gift means wishing for happiness. The stone gives optimism and self-confidence, helps to choose friends, attracts the object of love, sharpens intuition. In ancient times, it was noticed that amber burns and emits smoke with a pleasant smell. Many people are familiar with the word "frankincense", but few people know that frankincense is precisely the smoke from burning small, worthless amber. It was used in wedding rituals and other solemn occasions. Amber is a fossil fossilized resin of ancient coniferous trees, which has preserved its purity, transparency and bright color in the coastal sand sediments. Amber is called succinite, as the pine, from the resin of which amber was formed, is called "pinus succinifera" in Latin. Baltic succinite is the most common. Close to it is the amber of Ukraine: Rivne, Zhytomyr, and Volyn regions, Kyiv, Kharkiv regions, and the North Sea coast. All other fossil resins found in various deposits are named according to their location - Baikal, Sakhalin, Greenland, British, Mexican, Brazilian, Sicilian, etc. amber. Special names are aikaite, almashite, ambrite, ambrosite, beckerite, birmite, walkhovite, etc. - these are only amber resins. Amber is often called any fossil resin [1-34, 42, 55].

The history of amber fishing in the Baltic goes back several thousand years.

A large amber mining enterprise is located in the Russian Federation in the village of Yantarny, which is located in the Kaliningrad region of Russia. Development of this deposit began in 1872. Baltic amber yields 100-700 tons of raw amber every year.

Amber deposits are located in marine and coastal placers. Amber is washed by sea waves from the clay that is in the bowels of the earth, pieces of amber are thrown ashore. It is a well-known fact that in 1862, two tons of amber were found on the shore near the village of Yantarny after a storm. According to average data, up to 38 tons of amber are produced per year in the Kaliningrad region, but the main extraction of amber is carried out by an industrial method.

The most ancient way of extracting amber is quite simple: pieces of gem thrown out by the sea were collected on the sea coast. Especially a lot of stone was found after sea storms. In the western part of the coast of the Kaliningrad Peninsula, the sea provided approximately 75% of the total amount of amber. According to estimates, sea waves annually wash 36-38 tons of amber from the bottom to the shore.

The first mentions of land extraction of Baltic amber date back to the middle of the 16th century. Pits were dug on the shore until amber and groundwater appeared, the gem floated in the water and was collected by saka.

In the middle of the 18 th century attempts were made to extract amber from coastal ledges. But the tunnels built in the cliffs were unstable and soon filled up with sand deposits that covered the amber-bearing layer.

In 1467, privileges for the free collection and digging of amber were established for the northwestern lands of Poland. In the second half of the 16th century amber was mined by scooping. Stone miners went out to sea in boats and looked for accumulations on the bottom between the stones (in calm water, the gem is clearly visible at a depth of up to 7 m). One of the hunters loosened the soil with a long stick, and the other collected floating amber with a sack. In the areas of the seabed, where there were outcrops of blue earth, extraction was carried out with the help of a kesale - a net attached to a horseshoe-shaped arc. Kesale was installed between two boats, while moving, she furrowed the bottom of the sea with a net, loosened the productive layer and collected stone from the bottom.

Amber was mined underground in Polish Pomerania in the 17th and 18th centuries. The depth of laying tunnels was 1-5 m (some - up to 20 m). Even then, dredges were used when digging tunnels. Later, preference was given to open development. Thus, in 1840, 60 amber mines operated in Kurpy.

In 1871, the first mine with an extensive system of inclined and horizontal workings was laid near the present village of Sinyavino. But she never discovered the amber-rich areas of the blue earth. After seven years, the mine was closed due to its unprofitability. In the first half of the XIX century. amber extraction in this area was carried out with the help of small open pits. The most stone-rich areas of the coast were opened by small quarries that operated throughout the year. Extraction of the gem in this way proved to be successful and continued with interruptions for about 50 years.

The use of earthmoving machines (middle of the 19th century) significantly increased the extraction of amber. At the end of the 19th century such machines were successfully used by a special firm for excavation of the seabed in the Curonian Lagoon. The amber, together with the surrounding rock, was scooped up by nine steam engines and three manual machines, taken to the shore, where it was selected and sorted. The firm also had an amber mine in Palmniken and a diving facility in Schwarzrote. In this way, up to 75 tons of gems were mined per year.

Until the beginning of the XX century. underground development of amber-bearing layers became technically unprofitable. It was continued at the Anna mine, which was closed in 1922 due to difficult mining conditions. But somewhat earlier, in 1912, a deep (up to 50 m) quarry was laid for the open development of the deposit, north of Palmniken (the modern village of Yantarne), 1,5 km east of the sea. The amber-bearing layer lay 7 m below sea level under a layer of covering rocks with a thickness of up to 30 m. Excavation work was carried out with multi-bucket excavators. They scooped up the blue earth and loaded it into the open cars of the electric train, which went along the inclined track to the enrichment factory. Excavated rock was filled in the created space. This method of amber mining existed until 1944. The area of the deposit named

"Prykarierna" was developed for 60 years (until 1972). From 1880 to 1938, 7,734 tons of amber were mined at the deposit. Of the 600 tons of other fossil resin mined in the year before World War I worldwide, 500 tons of amber came from the Baltic States.

The Second World War caused losses to the national economy of the Baltic States. The retreating German troops destroyed the factories, destroyed the machines and pumps, liquidated the water supply and power plant, and flooded the quarry. After the reconstruction in 1948, the quarry yielded the first amber. On the basis of the deposit, a plant was created in the village of Amber, where all work was concentrated - from the extraction of amber to its artistic processing.

After detailed exploration of the Beach area, the plant started its operation. The deposit had productive rocks at a depth of 8-10 m with a high (about 2 kg/m^3) amber content. In 1977, a section of the Primorsky field began to operate with much larger reserves. On it, the layer of blue earth has a thickness of 6-14 m, the gem content is up to 2,5 kg/m^3, and the depth of the blue earth is 40-60 m. Both areas were developed by the open method. The mining process consisted of several operations. Excavated rocks in both quarries are removed with the help of hydraulic monitors and earthmoving machines. Hydromonitors use a powerful stream of water to wash away the covering rocks, turning them into pulp. The dredger drives the pulp through the pipeline into the sea and squeezes the water column of the Baltic in the western direction. This makes it possible to carry out work on areas that were previously under the water column [1,2,13,14,15,25].

In the Rivne region, at the Klesiv deposit, amber-bearing deposits are taken out with an excavator. The extracted rock is delivered to the washing unit located on the industrial site by motor vehicle. First, the rock enters the loader, from which it is fed on a conveyor to a screen equipped with a metal grid with square cells with a diameter of 5 mm. Above the screen at a height of 20 cm from the grid, a system of tubes is installed, into which water is supplied by a pump under pressure. It waters the rock, washes out clay, sand, silicon, fragments of crystalline rocks and amber less than 5 mm in size, taking them to a specially prepared quarry. Pieces of rock and gem 5 mm and larger are sent by conveyor for development. Here, the amber is manually separated from the rock containing it. Since 1980, more than 100 kg of mineral has been mined annually at the deposit, 95% of the mined amber belongs to the jewelry category [30,34,42,45,54].

The most energy-intensive and costly process is the removal of the slag rock, which does not represent much value for the enterprise, but the cost price of amber at the same time increases.

Physical, mechanical and chemical properties of amber.

Amber is a high-molecular compound of organic acids containing an average of 79% carbon; 10,5% hydrogen; 10,5% oxygen. Its formula is $C_{10}H_{16}O$. 100 g of amber contains 81 g of carbon; 7,3 g of hydrogen; 6,34 g of oxygen, little sulfur, nitrogen and minerals. In the process of oxidation (weathering), the content of oxygen in amber increases, and the content of the remaining components decreases. 24 chemical elements (Y, V, Mn, Cu, Ti, Zr, Al, Si, Mg, Ca, Fe, Nb, P, Pb, Zn, Cr, Ba) were detected in amber as impurities (from traces to 3%) , Co, Na, Sr, Sn, Mo, Yb). Of them, 17 were found in the lowland amber of the Klesiv deposit, 12 in the amber of the Beach area of the Primorsky deposit, 11 and 13 in the amber of the Curonian Spit and Prykarpattia, respectively. The smallest amount of chemical elements is contained in transparent amber. This mineral can be white, yellow, greenish, blue, red, but orange and golden-yellow varieties are typical. The mineral is amorphous, soft (hardness 2,2-2,5 on the Mohs scale), viscous, easily ground and polished. Its density: 1,05-1,096 g/cm^3. In terms of classification, this mineral is a representative of the group of combustible minerals - humic coal of the "liptobiolite" class. Chemically, it is a high-molecular compound of organic acids with the approximate formula $C_{10}H_{16}O$, usually with sulfur impurities. Amber softens at a temperature of 150 °C, and melts at more than 300 °C. It burns easily, giving off a resinous smell. The mineral has dielectric and heat-resistant properties, occurs in nature in the form of grains and pieces with a size from 1 to 10-20 cm or more in diameter, but very large pieces are also found - up to 10 kg in weight. The shape of the pieces can be any: drops, icicles, influxes of various irregular shapes, porous plates [13-15, 25, 45, 49-51, 56, 58, 61-67].

The elemental composition of amber from the beach area of the Primorskyi (Southern Baltic) and Klesivske (Ukraine) deposits, manifestations of the Carpathians and Prykarpattia is similar. The average content of the main components (C and H) in them is 80,78% and 10,12%, respectively; 78,05% and 955%; 79,8% and 10,07%; 78,26% and 9,99%.

Ukrainian amber contains up to 3,19% sulfur.

In the scientific literature, the term "Baltic amber" or "succinite" usually refers to resins containing succinic acid. The content of succinic acid in Baltic amber (succinite) ranges from 3 to 8%. Depending on the type of amber, it is distributed differently. Succinic acid is contained in transparent amber from 3,2 to 4,5%, in Bastardo - from 4,0 to 6,2%, in bone amber - from 5,5 to 7,8%, in oxidized crust - 8,2 %. The composition and structure of amber continue to be studied. Its volatile part (about 10% of the mass) has been known for a long time. These are aromatic compounds - terpenes with 10 carbon atoms and sesquiterpenes with 15 carbon atoms in the molecule. As mass spectrometric studies have shown, more than 40 compounds are part of amber. Many of them are not yet known. Pure abietic acid and its isomers were isolated from amber. They make up the part (20-25%) of Baltic amber soluble in organic solvents. Mineral inclusions in amber are represented by iron sulfide - pyrite and bituminous substance. Among the gas inclusions in amber, CO_2 was found; O_2; H_2; Ar; Cr; Xe; Ne, among which nitrogen predominates. A residue of amber, insoluble in any of the known solvents. IR spectrometry data showed that "succinite" contains lactone (ester) groups, that is, it is an ester. In addition, amber constantly contains succinic acid (about 4%) and impurities of salts (mainly succinic) of potassium, calcium, sodium, and iron (up to 1%). Thus, amber consists of three groups of compounds: volatile terpenes and sesquiterpenes; soluble organic acids; of insoluble polyesters of these acids with alcohols formed from the same acids [52, 59-62].

Rivne amber differs in its chemical composition. It is the most saturated with impurities and includes 18 chemical elements. In addition to silicon, magnesium, iron, calcium, which are present in almost all deposits, lead, zirconium and up to 3,19% sulfur are added. The ash content of Klesiv amber is 8,7%. This affects the quality and color of the cured resin. Amber is a mineral of the class of organic compounds, the resin of coniferous trees mainly of the

Paleogene period. Composition of amber: volatile aromatic oil, two soluble resin fractions, succinic acid and 90% of insoluble fractions. Its chemical formula is $C_{25}H_{40}O_4$. Amber is an amorphous polymer, has many colors, gives a specific IR spectrum (within 700-1900 cm^1), which distinguishes amber from other similar resins. Melting point t=365-390°C. The specific gravity is 1000-1100 kg/m^3 (970 kg/m^3 is found in the Baltic region, and 1220 kg/m^3 in the Carpathians). It is well amenable to mechanical processing. It does not dissolve in water (partially in alcohol - 20-25%, ether - 18-23%, chloroform - up to 20%), but it can swell and increase in volume up to 8% with prolonged stay in it. Completely decomposes in hot concentrated nitric acid, can be softened and at t=100°C.

The value of amber depends on the uniqueness of the amber samples and is established collegially by experts.

Geological features of the location of amber deposits

The main types of amber and fossil resin deposits are marine and littoral placers, occurring in sediments ranging from the Lower Cretaceous to the Quaternary. Marine amber deposits are located on the Baltic coast, in Ukraine, Siberia, Mexico (Fig. 1), the Dominican Republic (Figs. 2,3), and Burma. Coastal seas are widely distributed along the shores of modern seas and oceans.

Amber ("Burmite") from Myanmar's Hukawng Valley has been known since at least the 1st century AD. The hill (Noije-bum), which has been known as an amber deposit since 1836, is currently being developed.

Several groups of geologists visited this area with research between 1892 and 1930. All of them believed that the deposit contains tertiary amber rocks. However, recent studies have shown deposits of Cretaceous age. Insects are found in the amber, a famous sample of the ammonite Mortoniceras, which was discovered during the visit of a group of researchers to the deposit.

The amber deposit is located in the Hukawng Basin (Myanmar), which consists mainly of composite sedimentary (volcanic) rocks of the Cretaceous and Cenozoic ages. The deposit contains many fragmentary sedimentary rocks, with thin limestone layers and a layer of carbonaceous material. Sediments are located in a coastal marine area, such as a bay or a river mouth.

Amber is found in the form of pieces, mainly in the form of disk fragments [2].

In Europe, a large deposit of amber is located in the Kaliningrad region of Russia. It has no equal not only in terms of explored reserves, but also in gem concentration (on average 2 kg/m^3). The processing plant, which operates on its base in the village of Amber provides about 90% of the world production of this stone [1-5].

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Fig. 1. Mexican amber weighing 3472 grams

Fig. 2. Dominican amber deposit

Amber deposits are located at a depth of up to fifty meters, as a rule, they are layers about twelve meters thick. Going far into the sea, this layer is eventually washed away by water, which leads to the emergence of amber on the surface.

In nature, amber is found in the form of amorphous bodies of various shapes and sizes. The weight of amber found in nature can be from a fraction of a gram to several kilograms. And the world's largest "Burmese amber" can be seen in the Natural History Museum in London, weighing 15 kg 250 grams.

Fig. 3. Dominican raw amber

There is amber and an unusual blue color. This very rare and exceptionally beautiful amber is mined in the Dominican Republic, Mexico and Nicaragua. On a light surface, amber casts a soft blue, and on a dark one, it changes its color to rich blue. It has a natural ability to glow in the dark, which is associated with the presence of volcanic ash in it. The difference in the color of tropical amber compared to Baltic amber is explained by the fact that yellow amber was formed from the resin of pine trees, and blue amber - from carob resin.

The Russian Amber Museum, located in the "Don" tower in Kaliningrad, has collected several thousand amber exhibits, including an amber nugget weighing 4 kg 280 g. This is the second largest whole piece of amber found during the entire period of its mining. In the Lithuanian city of Palanga, the Amber Museum is located in the Tyshkevych Palace. The rich collection includes 5 thousand objects occupying 15 rooms. Here you can also see the "Amber Sun" - a nugget weighing 3,5 kg. The most famous amber museum in Central America is the Mexican Museum "Hidden Stone". It contains 10,000 samples of amber with inclusions of algae, shells and even fish.

Small deposits are located on the shores of the Bay of Gdańsk in Poland and on the coast of the North Sea in the Netherlands, Germany and Denmark. The gem content in the Stubbenfelde deposit on Usedom Island is 0,357 kg/m^3. In Poland, amber is mined from coastal deposits along the Gulf of Gdańsk. Significant deposits of Lower Miocene amber are found in Western Pomerania in the Slupsk region.

The depth of the blue earth is greater, the farther from the coast of the Baltic Sea. If in the northwest near the village of Filino the amber-bearing rock is exposed at the base of the coastal ledges, then in the western direction it lies at a depth of 80-100 m from the surface.

The Paleogene layers of the Southern Baltic represent only a part of the huge amber horizon, which is exposed in Belarus (in the Minsk and Grodno regions) and in Ukraine (the Klesiv deposit in the Rivne region). The presence of this horizon was confirmed by drilling operations carried out on the territory of Poland, in particular in Eastern Primorye and the vicinity of Braniev, as well as in Western Pomerania between Slupsk and Koszalin. The German researcher H. Konventz believes that the amber rocks continue in the western direction to the coast of England [45-53].

In Ukraine, amber has been known for a long time. Its first developments are known near Kyiv (Mizhhirya and Vyshhorod region) and in Volyn (near modern Klesiv). In 1870, near Kyiv, 50 pieces of gems of different sizes, weighing a little more than 800 grams, were found in one layer. Amber was washed by the Dnieper and other rivers during the flood, carried away by meltwater and rainwater from streams and ravines. In ancient times, its extraction not only satisfied local demand, but also made it possible to export it to ancient countries along the shores of the Mediterranean Sea and to eastern states. However, near-surface development of small Kyiv deposits, accessible to miners, were gradually developed and forgotten [45-47].

Small deposits of amber have long been known in the western regions of Ukraine on the territory of the present Lviv and Ivano-Frankivsk regions. Red amber was found in the Tertiary deposits of Lviv and its surroundings as early as the middle of the last century. Amber was not only mined along the Dnieper and its tributaries, in Volyn and Transcarpathia, but also processed in these places. Kyiv amber was not inferior in composition and properties to Baltic amber. That is why it was sometimes called Kyiv succinite.

Currently, amber is found in Neogene deposits covering sulfur ores in the Yaziv, Nemyriv, Rozdil and Podorozhnen deposits and in the Rechichan sulfur deposit. There are more than 2,000 gem pieces ranging from a millimeter to 25 cm in size in the Yazivskoye deposit pit.

Amber is colorless, yellow-white, yellow, brown-yellow, light and yellow-brown, transparent, translucent and opaque. A change in the degree of transparency of the stone by section was observed. Transparent amber is concentrated in its middle [45-49].

Geotectonically, the Klesiv amber-bearing zone is located at the junction of the northwestern slope of the Ukrainian Crystalline Massif, the Volyn-Podilsky Plate and the Pripyat Depression and has a two-tiered structure. The morphology of the modern surface of the crystalline base is determined by its structural position on the northwestern slope of the shield.

In the area of project works, the crystalline foundation is covered by Cenozoic and Quaternary sediments and has absolute elevations of 130-170 m above sea level, gradually dipping in the northern and western directions with a slope of 10 m per 1 km. The general tendency to dip is complicated by individual local uplifts of the shield protrusions. The crystalline foundation consists of ultrametamorphic, metasomatic and intrusive formations of the Lower and Middle Proterozoic.

The large-brick nature of the foundation relief is established with the development of oval, isometric, or irregularly shaped projections of Precambrian rocks with an area of 1 to 10 km, separated by relatively narrow (the first hundred of meters) and elongated (the first kilometers) depressions. In the modern relief, they correspond to swampy valley-like areas, the relative excesses of the foundation protrusions above the adjacent depressions are on average 10-12 m. The leveling of the foundation relief takes place due to the accumulation of sedimentary deposits of the Paleogene age in its depressions. An intermittent layer of bluish-gray, sometimes greenish-gray, dense, viscous clay up to 2,5 m long lies on the weathered crust of crystalline rocks. The age of the clay is Lower Oligocene. On clays and in places where they are absent, on the crust of weathering of crystalline rocks, there are two layers of glauconite-quartz sands of Oligocene age of different color shades, which are a productive horizon. The lower layer of amber-bearing rocks is represented by shallow-medium-grained sands of dark gray, sometimes greenish color and medium-grained sands of dark gray color with a bluish-gray tint. The rocks are saturated with water, the thickness of the layer ranges from 1,0 to 6,0 m. In the lower part of the section, thin (2-3 cm) layers of black humus matter are noted.

The upper amber-bearing layer is represented by shallow-medium-grained gray, light-gray sands saturated with water, which contain a significant amount of humic matter unevenly distributed over the layer. In the section, there are thin (1-3 cm) layers of lenticular clays, as well as the remains of plants and roots. The average thickness of the layer is 2,0 m. Oligocene deposits are overlain by a horizon of Quaternary formations, which are represented by light-yellowish-gray, gray, light-gray fine-grained quartz sands of fluvioglacial genesis. The thickness of the layer of Quaternary deposits varies from 1 to 8 m.

The hydrogeological conditions of the Klesiv deposit are relatively simple, the upper groundwater aquifer is developed everywhere, the source of which is atmospheric precipitation. Water-bearing rocks are represented by fine-grained Quaternary sands and fine-medium-grained sands of Oligocene age. The thickness of the horizon reaches 12 m. In the lower part, it is a pressure float. In the greater part of the territory, dark greenish-gray clays of early Oligocene age or structured kaolinized crust of weathering of crystalline rocks are waterproof.

According to Ukrainian geologist V.I. Panchenko [45-49] The Klesiv amber deposit is located in the zone of Proterozoic crystalline rocks of the northwestern part of the Ukrainian shield surrounded by Paleogene sedimentary formations. The placer consists of several areas, two of which are open quarries. The productive horizon of the deposit consists of three sand layers composed of different-grained quartz sands, which are unequally enriched in clay, organic material and amber. The lower layer is sporadically enriched with glauconite, which gives the amber-bearing rock a blue tint. Pieces of amber reach a size of 10 cm. According to V.I. Panchenko and O.S. Tkachuk, the amber content in the deposit is from 15 to 310 g/m^3 and even 1000 g/m^3, the average is 50 g/m^3. The distribution of amber is uneven, the maximum concentration is at the base of the layer. Annual extraction of amber at the Klesiv deposit does not exceed 140 kg (Fig. 4). In a short time, Klesiv amber gained recognition on the domestic and foreign markets.

Fig. 4. Polish amber

Unlike Baltic amber, Klesiv is much further away from the sea. It can be predicted that in Paleogene times there was a sea shore not far from the village. The position of the ancient coastal strip in Volyn is also recorded by other finds of amber in this area. It is known that vertical tectonic movements of the Earth's crust took place on the border of the Eocene and Oligocene, which led to the transgression (advance) and regression (retreat) of the sea. German researcher F.

Kaunhoven found that in the Tertiary period on the territory of the current Kaliningrad Peninsula, the interpenetration of sea and land changed 19 times.

In the post-Oligocene period, amber deposits were exposed to denudation factors, it was carried away by water into new deposits. During the Ice Age in the southern Baltic region, part of the deposits was pushed away from the main deposit by the moving glacier. Glacial waters and moraines carried pieces of rock with amber to different countries of Europe. Outcrops of such rocks coincide with the boundary of glacial deposits, which lie on the border of Tertiary and Quaternary deposits. The discovery of small deposits of amber in Poland and Germany is connected with this process.

Amber-bearing rocks on the underwater slope of the Kaliningrad Peninsula are still exposed to the active action of sea waves. A lot of amber is washed up on beaches on a large part of the southern coast of the Baltic Sea. The researchers claim that amber finds on the territory of Belarus are connected with fluvioglacial, lake-marsh and coastal-sea deposits of the Cenozoic age. According to the combination of paleotectonic, facies-paleogeographical data and the results of testing, two amber-bearing regions have been identified in Belarus - Poliska and Mykashevitsko-Zhytkovyka.

2. Characteristics of amber deposits in Ukraine

According to research data [45-53], three zones and four districts with industrial concentrations of amber were found in the Rivne region. All of them belong to the Pripyat basin of sedimentation, in which large-scale amber placers were formed simultaneously with the accumulation of marine sediments in the Oligocene epoch (about 35 million years ago). The total area of productive amber-bearing horizons in the Rivne region is 3,810 km^2, which is 18% of its territory.

In the Rivne region, two amber deposits have been explored: Klesivske in Sarnenska and Vilne in Dubrovytsa districts, which are currently being developed by the state enterprise "Burshtyn Ukrainy" [45-49].

Further growth of raw amber reserves is possible due to the completion of the stage of prospecting and prospecting and evaluation works at the "Fedorivska" and "Melioratyvna" sites within the Klesiv deposit and the areas of the Volodymyrets amber-bearing zone, where work has been carried out by the "Rivne Geological Expedition of the North-Geological State Enterprise" since 1988.

The largest amber deposits "Klesiv", "Vilne", "Volodymyrets-Skhidny" contain at least several hundred tons of amber raw materials, of which 128 tons of industrial reserves have been explored. Two of them are exploited: Klesivske deposit (site "Pugach") is developed by the state enterprise "Burshtyn" of Ukraine", "Volodymyrets-Skhidny" - LLC "Center "Solar Craft". The official production of amber in 2015 was 4,5 tons.

In the Klesiv deposit, amber is mined using an open pit method (Fig. 5). Amber lies in sandy soil. The depth of occurrence is up to 15 m. There is a granite quarry with a significant supply of water near the deposit. The deposit is located close to roads and the power grid. During the first six months of 2003, 230 kg of mineral was mined at the State Enterprise Amber Mines. And already in 2006, amber extraction is 3,200 kg per year, which was achieved by using the new ESH-5/45 excavator for amber extraction and stable financing from the state budget. At the same time, for 2006, the volumes of works in the quarry are: excavation works - 23,6 t/m^3; mining mass - 17,466 t/m^3; reclamation per month - 0,5 ha. [45-53]

However, due to the lack of funding, as of January 1,2017, the State Enterprise "Ukrburshtyn" practically does not work and is bankrupt.

Fig. 5. Preparation of the massif for extraction of amber in the quarry by excavation method

Polish amber differs in its chemical composition. It is the most saturated with impurities and includes 18 chemical elements. In addition to silicon, magnesium, iron, calcium, which are present in almost all deposits, lead, zirconium and up to 3,19% sulfur are added. The ash content of Klesiv amber is 8,7%. This affects the quality and color of the hardened resin [36-41].

Amber is used for the manufacture of jewelry, varnishes, paints, medicinal preparations are made from amber. In 1998, the first Rivne jewelry factory was put into operation, which, in addition to amber jewelry, produces succinic, glutaric acids and volatile aromatic oil, which is used in pharmacy.

Potential reserves of amber in the region are much larger. According to the results of the exploration and evaluation work of the Rivne KGP of the SE "Ukrainian Geological Company", the estimated amber resources in the Dubrovitsa, Sarne, and Volodymyrets districts alone amount to more than 1,400 tons.

The number and total area of the areas for which special permits for geological study, including research and industrial development of subsoil were issued to subsoil users as of the beginning of 2016: state - 3 and 46,5 km^2; private - 2 and 68,4 km^2, respectively. The total area of amber-prospecting sites offered to the Ukrainian Geological Company for geological study is about 800 km^2. Thus, 685 km^2 of amber-bearing areas of the region are not controlled and are objects of unauthorized development.

As of 2009, the total area of areas affected by unauthorized amber mining was 374 ha. Now, according to approximate estimates, it exceeds more than 1,000 ha and is growing, but their accounting and auditing is not carried out.

3. Conditions of accumulation of primary amber deposits in amber-bearing areas of Rivne region

Amber accumulation conditions within the Oligocene sedimentation basin of the Rivne, Volyn, and Zhytomyr regions are determined by the features of the geological structure of the northwestern slope of the shield and the features of the structural and morphological structure of various parts of the Intermountain Sea. This section is provided based on research materials of associate professor M.V. Krynytska, prof. Melnychuk V.G., Nesterovsky V.A.

and studies of the Rivne KGS SE "Ukrainian Geological Company" [45-53, 65].

Primary amber placers of the Klesiv district

The discovery of industrial amber deposits in Ukraine began with the discovery of the Klesiv deposit in 1980, which is still active today. Further prospecting and prospecting and evaluation work within the Klesiv amber-bearing district, which was carried out over the past 30 years, expanded information about its geological structure and the conditions for the formation of primary amber deposits.

The Klesivske deposit is tectonically located within the lowered part of the Osnytskyi block - the Klesiv graben [45-49, 61]. The negative structure is small in size (according to geological surveys - 240 km²), has a shape close to a regular quadrilateral and is limited by faults. It is separated from the shield by Shahynska [45], and to the west it is bordered by Mylyatka by meridional local tectonic zones. Within the limits of this inherited subsidence are mainly all (except for the manifestation near the village of Perebrody in the north of the district and the Tomashgorod manifestation in the east) currently discovered amber manifestations within the Klesiv amber-bearing district.

Productive (intermontane) sediments of the southeastern part of the Klesiv district (Pugach, Rodnikova, Duny sites and the Fedorivka manifestation) fill the depression between the outcrops of Proterozoic crystalline formations and their weathering crusts. The productive deposits of the Klesiv deposit proper lie in a strip from 200 to 700 m wide, which is traced from the southeast to the northwest between the exits to the sub montane surface of the small ledges of the foundation. The length of the amber-enriched strip is more than 2 km. Outcrops of crystalline rocks among intermountain sediments are insignificant in size and in intermountain time represented numerous abrasion islands [45] with an area of about 50%.

In the complete sections of the Cenozoic of the Klesiv deposit, on the Proterozoic crystalline rocks of the Osnytsk complex, their weathered crust or chalk deposits, the Upper Eocene Obukhovian deposits, formed in relatively deep-sea conditions, are located, which are replaced by sands formed in shallow sea conditions up the section.

The amber-bearing stratum productive of industrial contents is a stratum of sands of early and middle Oligocene age [45-47]. The sediments are usually limited to paleo-depressions between the crystalline protrusions of the basement and lie on a thin (up to 15 m) layer of Obukhov sediments, represented by glauconite-quartz sands and clays. The thickness of the Obukhov deposits decreases on paleo highs, where they are represented by clays or clays underlain by layers of sand that are insignificant in thickness. The depressions in the roof of the clayey Obukhov horizon are sometimes filled with fine-grained, clayey sands of a dark green color. Amber-bearing sands are multi-grained, mostly fine-medium-grained, gray, dark gray, greenish-gray in color, sometimes with a content of up to 3-5% flint and fragments of crystalline rocks. Amber fragments of various shapes and sizes, with an oxidation crust up to 1-2 mm. Sizes are mostly 1-2, rarely 5-10 cm. Contents (according to the Zahidkvartssamotsvity VO) range from 1 to 420 g/m³.

The amber-bearing deposits of this amber-bearing region contain a small (mainly 0,5-1%) amount of glauconite. According to the data of Zahidkvartssamotsvity [450-53], the frequency of detection of glauconite in studies of the electromagnetic fraction of samples is 69%, including 50% in the light fraction. The glauconite of the light fraction is mostly rounded and rounded-angular, rarely in the form of intergrowths, which indicates the erosion and over wash of bottom sediments formed in the conditions of the deeper shelf of the Obukhov Sea.

The productive stratum, which is somewhat uniform in lithological characteristics, is divided into two slightly lithologically different parts when studied in detail, taking into account the structural and morphological features of the bottom of the sedimentation basin and the abrasion-accumulative nature of sediment accumulation.

According to the data of Zahidkvartssamotsvity [45-49], the lower part of the horizon (700 m long) of the Velikiy Pugach section of the Klesiv deposit is represented by fine- and medium-grained sand of a predominantly greenish-gray color, with a glauconite content of up to 5%. The thickness varies from 1-2 m to 5-6 m. Among the sand, there are dark gray to black (2-3 cm) patches, enriched with scattered carbonaceous material and, mainly, with amber. Amber is mostly run-in. Pebbles of foundation rocks and black flint (3-5%) are found at the base of the horizon.

The upper part of the horizon is represented by fine- and medium-grained gray sand, with patches of light gray; carbonaceous organic matter is scattered unevenly, there are 1-2 cm thick clay patches and chaotically arranged fragments of charred wood. Power from 0,5 to 1,6 m.

In the northwest of the field, the productive stratum can be traced between two islands composed of foundation rocks and located at a small distance from each other. The Mezhyhirska stratum is limited to the central parts of the paleoduct. The upper part of the stratum, with a thickness of 0,6-1,9 m, is represented by variegated sands of gray, dark gray, and sometimes greenish-gray color. Amber was not detected in this part of the stratum within the investigated section. In most cases, amber is found in the lower part of the stratum, the thickness of which varies from 2,7 to 4,3 m. The lower greenish-gray part is lithologically similar to the upper part, but there are samples enriched with scattered carbonaceous matter and fragments of carbonized wood.

Probably, the bottoms of the productive layer were formed in coastal-marine conditions at the beginning of the intermountain time. Amber resin washed from the stable mainland and the territory of the islands accumulated in the channels between the islands. Within wide channels with a slow hydrodynamic regime (Velikiy Pugach area), amber resin entered the sea basin along with the seasonal removal of terrigenous material from the main shore and islands. The removal of the resin into the open sea was prevented by the differences in the seabed and the ability of amber to sink in desalinated water. The connection with the open sea contributed to the inflow of seawater and the formation of a geochemical environment favorable for the final fossilization of amber. The absence in the sediments of narrow paleochannels of pebbly and crushed stone formations, checkers containing carbonaceous matter indicates an increase in the speed of currents in such channels. Amber in these zones of the shallow sea was eroded when the low-lying terrigenous zones of the islands were flooded.

The upper parts of the productive horizon were probably formed at the end of the intermountain time during the reduction of the area of the islands, the expansion of the straits, and the leveling (reduction of elevation differences) of the seabed in the straits.

Near the slopes of paleo-elevations and on washed-out paleo-elevations, the lithological characteristics of amber-bearing sediments are different - the sands become clayey. The color varies from dark gray to gray and bluish gray. On the section, these deposits occupy a hypsometrically higher position and are separated from the sediments formed in the channels by a layer of dark gray clay, 0,3-0,5 m thick, which in some places within the district increases to 6,0 m.

According to the lithological and paleogeomorphological studies of I.O. Maidanovych [55] clays mark the beginning of the transgression of the Berek Sea, and the bluish-gray sands, in which rolled fragments (1-5 cm) of flint and gray quartz, samples of carbonaceous matter and amber, are also found, belong to its regressive stage.

However, the materials of the exploration and evaluation works of the Rivne KGP of the SE "Ukrainian Geological Company" over the past two decades at the Oleksiivka and Tomashhorod manifestations allowed to investigate in more detail the structural and morphological and clarify the lithologic and facies conditions of the formation of amber deposits within the northwestern edge of the shield.

We attribute the lower part of the productive horizon to the terrigenous deposits of the shallow coastal zone of the Kharkiv Sea, formed at the beginning of its regressive stage (intermountain time). The upper part of the stratum belongs to deposits formed in conditions of a more open sea. The litho-facies section reflects the transition from the sediments formed in the conditions of a sea channel to the sediments of the flooded coastal zone of the islands - the intermontane stratum, represented by dark greenish-gray, fine-medium-grained sand (lower stratum), is replaced by dark gray dense clay, which is higher in section and in the direction of paleo-islands is replaced by bluish-gray, clayey sand. Sediments covered with gray and bluish-gray sand were formed at the same time as the upper layer within the blurred terrigenous zones of paleoislands. The sediments probably acquired a bluish color due to erosion of the weathering crust of crystalline rocks.

At the end of the regressive stage of the intermountain sea (Middle Oligocene), the shield area underwent minor subsidence, and the crystalline abrasion remains within the sea underwent significant destruction. Thus, the sea in the stage of regression transgressed into low-lying insular and coastal areas (beaches, river deltas, coasts of lagoons and bays) and the coastline, accordingly, receded to the east. A new coastal shallow zone was formed, in which the processes of converting fossil resin into amber continued.

This assumption is also confirmed by the fact that for the greenish-gray, dark-gray sands lying hypsometrically below, 1-5 cm thick black carbonaceous matter, which is often associated with increased amber content, is more characteristic, and bluish-gray sands are characterized by the presence carbonaceous matter unevenly scattered throughout the stratum and clay samples. Oblique layering was sometimes noted in the hypsometrically higher sands, which also confirms the gradual migration of the coastline.

According to the data of the Department of Fossil Flora of the Institute of Geological Sciences of the Academy of Sciences of Ukraine [45-49, 64], the age of the sands of the productive layer is Lower-Middle Oligocene.

To the north-east of the Pugach section, in the Duna section, the productive stratum forms a layer to the local depressions of the crystalline basement. Here, an increase in the strength of the underlying clays and an increase in the strength of the most productive stratum is noted.

In terms of litho-facies, the sections of the Klesiv deposit belong to the terrigenous facies of the coastal zone of the shallow shelf, formed within the straits between the islands and near-island beaches, as well as the submerged terrigenous zones of the islands.

On the Fedorivsky manifestation, located to the south of the Klesiv deposit, the productive deposits are represented by fine-medium-grained sands of mainly gray, dark gray color, with glauconite (up to 5%). There are also flints and fragments of crystalline rocks (3-5%) with a size of 0,4-1,5 cm, samples (1-15 cm) of black carbonaceous material with a high content of amber.

Amber pieces (from 0,3 to 5-15 cm) and marked macrofossils - fossilized cones of conifers from the Pinaceae family are found within the manifestation. The thickness of the productive stratum varies from 0,5 to 11 m. It is assumed that the productive deposits were formed during the flooding of the coastal parts by the sea and the mass removal of amber into the sea area. To the southeast of this manifestation, a paleo-depression filled with intermontane sediments "cuts" into the shield. According to Maidanovych I.A. [55] is the Fedorivska river paleovalley, in which gray and dark gray intermontane sediments without amber are common. Deposits of the Fedorivskyi manifestation are classified [55] as shallow-marine lagoon-delta deposits.

Litho-facies sections of the southern part of the amber-bearing area (Oleksiivka manifestation) confirm the conclusion about shoreline migration. The manifestation is adjacent to the edge of the shield and is limited in the east by outcrops of crystalline rocks of the foundation, in the northwest by the modern occurrence of Middle Eocene rocks.

Intermontane deposits, represented by medium-grained sand, with separate grains of glauconite and gravel grains of quartz. Taking into account the structural and morphological position of the bottom of the sedimentation basin, these sediments are classified as marine sediments formed in the zone of mobile shallow water of the wave field of the inner part of the sea (perhaps a large bay), which maintained a connection with the open sea.

Cross-sections of wells and shafts located further east in the lower part of the stratum contain multi-grained, clayey sands with admixtures of quartz gravel grains, glauconite grains, and crushed fragments of crystalline rocks. There are fragments of charred wood 0,5-15 cm in size and clay samples (5-10 cm thick) and lumpy fragments of dark gray plastic clay. Accordingly, the coastal zone was located further east.

With the erosion of the paleo-elevations and the gradual uplift of the territory adjacent to the shield, the coastline gradually moved to the east. The Intermountain Sea initially spread beyond the coastal embankment, into the zone of active wave influence and, further, into the coastal shallow water zone, limited by the main shore. With the active action of the waves, a new beach area was formed. The sea gradually flooded the land, washing loose sediments, soils, vegetation, including resin-producing ones, and amber resins washed from the soil into the sea waters.

To the west of the Oleksiivka occurrence, the Oligocene sediments are washed out, but the spread of Eocene Kyiv deposits and the absence of Obukhov deposits in the northwest, as well as the discovery of grain amber in the extreme western outcrops of the occurrence, suggest that the bottom of the intermountain sea was complicated by an underwater or island bar, which could prevent the transfer of fragmental amber to open sea

According to [45-47] detailed exploration of the Klesiv deposit, amber in all samples is represented mainly by angular, partially rolled fragments, which also indicates the formation of primary amber deposits in the immediate vicinity of the parent deposits of fossil resin by its washing when seawater enters the low shore. The fact of mass transfer of amber resin by water remains questionable. Amber sinks in fresh water and can only be transported in rivers by turbid bottom waters by pumping or dragging.

The distribution of amber-bearing deposits of the Tomashhorod manifestation (eastern part of the district) in the south, east and, partly, in the west is limited by outcrops of crystalline rocks of the foundation. Probably, in the intermountain time, their accumulation took place in the conditions of a bay. Lithologically, the deposits are represented by quartz sands and quartz sands with single grains of dark gray glauconite with a greenish tint, dark green color and dark gray clay siltstones. The sands are multi-grained, mostly coarse-grained.

The quartz grains are well rolled, quartz gravel, some feldspars and small pebbles of crystalline rocks are present. Characteristic tests of dense clays are greenish-gray, dark gray (to black). There are rolled fragments of charred wood and amber.

The extreme northern geological survey wells [21,45], drilled partly on the territory of Belarus, revealed erosion of Oligocene sediments. According to lithological features, deposits productive of amber were found at a considerable depth (12, 20-23 m) in the area of the village. Crossings [21, 46-50]. They are represented by gray, brownish-gray, coarse-grained sand (or medium-grained with layers of coarse-grained), quartz with glauconite and feldspar, with wood fragments and enriched gravel, sandstone pebbles, tuff sandstone, granite in the lower horizons. This manifestation is the extreme northeastern, potentially amber-bearing area, confirmed by finds of fragmentary amber. In tectonic terms, it is timed to the intersection of the local Veliko Lake zone [45-49, 61] with the South Pripyat fault. Probably, due to the action of neotectonic movements, the amber-bearing layer was lowered and covered by a thick layer of deposits of the post-Mezhyhirian period. The lithological features of the sediments allow us to assume that they were formed in the places of accumulative forms (overburdens, bars) of sedentary shallow water in the sublittoral zones and littoral zones of the islands.

Primary amber placers of Dubrovytsa district

The geological study of amber-bearing deposits of the Dubrovytsa amber-bearing district began in 1982-1983, when the Vilne deposit was discovered by the staff of the IGN of Ukraine. Since that time, a large number of wells and pits have been drilled within its borders, but practically no manifestations promising for industrial development, except for the Vilne deposit, have been found. However, a large amount of field material confirmed the complex geological structure of the area and the uneven distribution of intermontane deposits. The southern limit of the distribution of productive deposits is the erosion cut of Paleogene sediments within the Bielsky fault, in the north - the erosion cut of the Pripyat valley and its tributary, in the east - the erosion cut of the Horyn valley, and the western limit is timed to the Manevytskyi-Stolinsky, revealed by geological surveys [46-50] fault

In terms of structure, the Vilne deposit spatially gravitates toward the intersection of the northeast-trending Horyn tectonic zone with the latitudinal Bilsky tectonic fault and is located southwest of the Dubrovytsa ledge (a structural element of the North Ukrainian horst zone), broken by an orthogonal system of tectonic zones into smaller ledges, complicated in turn by by linear, low-amplitude steps of a northeastern trend [46].

The heterogeneity of the tectonic structure and tectonic activity in the pre- and post-Mezhyhirian times actually determined the complex geological structure of the deposit and the amber-bearing area as a whole.

According to the description of the exploration trench of the Southern section of the Vilne deposit [46], the productive intermountain stratum is represented by gray, dark gray to black, fine-medium-grained, quartz, clayey sand. Oblique layering of sands, emphasized by clayey material, and the presence of lenses of dark gray, black, recorded, thinly layered clay, enriched with the remains of partially charred wood, were noted. Findings of fragments and pieces of amber, mostly from 1-2 to 3-5 cm in size, rarely 10-15 cm, are associated with such lenses. Amber is also found in lenses formed by accumulations of wood remains, to which the largest amber contents are attributed, and also in lenticular samples of carbonaceous sand (often with fragments of charred wood). Fragments of branches and trunks, cones and bark are noted among the wood remains, which are sometimes replaced by pyrite or silica. The frequency of detection of glauconite according to the results of studies of electromagnetic fractions of the Vilne deposit is 66% (according to the data of the Zahidkvartssamotsvity).

The territorially remote (2 km) Northern (near the village of Kryvytsia) section of the deposit was formed under similar geological conditions. The thickness of amber-bearing deposits in this area is insignificant - 1-2 m and is represented by fine-, medium-grained, clayey, dark gray, dark greenish-gray sand, with lenses of brown, dark gray, dark greenish-gray clay, with fragments of carbonized wood, with pebbles of quartz, flint. Findings of amber are limited to clay lenses or to finds of wood fragments. According to the conclusions of individual geologists [46-55], the productive stratum of this area is assigned to the redeposited alluvial type based on lithologic-facies features (the presence of stratification, the presence of gray multi-grained sands at the base of the stratum). However, this assumption is not confirmed by structural and morphological studies.

The structural and morphological analysis of the pre-Cenozoic surface and the analysis of the depths and thicknesses of the Eocene (Kyiv and Obukhov) sediments allow us to assume the presence of a significant island located further east (within the Dubrovitsa ledge) and the possibility of resin-producing trees growing on it.

The occurrence of amber-bearing deposits is hypsometrically higher than in the Northern section, the density and variability of dark gray, fine-medium-grained, clayey sands (enriched in plant remains, carbonaceous and clayey samples) in the southern part of the deposit are bluish-gray, dark bluish-gray sands , greenish-gray, fine-medium-grained, clayey, with randomly arranged fragments of amber, indicates the formation of the latter at the base of the bar from the side of the open sea. These deposits are characterized by the absence of carbonaceous material. The hydrodynamic activity of the sea contributed to the increase of the overburden in height with marine sediments and terrigenous material brought from the side of the island. Let us assume that enrichment with terrigenous material also occurred from the side of the archipelago of the islands of the Volodymyrets amber-bearing district.

According to the modern structural and morphological study of the bottom of the seas, the formation of island bars is characterized by being tied to tectonic faults. As noted above, the Horyn tectonic fault runs along the territory of the deposit. In addition, other manifestations of the Volodymyrets amber-bearing district are spatially confined to it.

To the north-east of the Vilne deposit, with amber contents from 0,60 to 242,7 g/m^3 (on average 56,0 g/m^3), fragmental amber was found at the Mochulishche occurrence (in 11 shafts out of 22 passed, contents 1,0 36,5 g/m^3) and at the Khutirskyi exposure (in 17 pits out of 99 passed, contents 2,2-51,6 g/m^3) in dark gray sandy-clay deposits of the Lower Oligocene. The discovered amber is usually flattened, mostly angular, slightly rolled and not rolled, with an oxidation crust up to 1 mm. Timed, in the predominant amount, to tests of clay and carbonaceous matter. These deposits are also classified as those formed under the conditions of accumulation of terrigenous material within the surface and underwater parts of the island bar, which may have continued from the Vilne deposit in the northeast direction.

Similar facies formations were also found in the northeastern part of this amber-bearing area during prospecting works on the Zolote, Yasinets, and Osova manifestations [46]. The sediments are characterized by the absence of a coarse-grained sand component and psephitic particles and are represented mainly by fine-grained sand, rarely medium-grained. Loose sandy rocks lie on deep-water (siltstones, clays, fine-grained silty sands) sediments of the Obukhov regional. These manifestations were found to the northeast of the manifestations described above and presumably continued the ridge of surface paleouplifts with submarine ones under the conditions of increased depths of the open shelf.

By prospecting wells [46-49], drilled 2-3 km north of the Vilne deposit (on the outskirts of the villages of Litvytsia, Tryputnia), Oligocene amber-bearing sediments overlap with Miocene continental sediments and are found at a considerable depth or are completely absent, while marine formations are revealed at their characteristic modern hypsometric levels Upper Eocene. Such features of the geological structure are justified by the different amplitude of adjacent structural blocks and their inheritance in the plate stage of development, as well as neotectonic movements in the post-Mezhyhirian period. According to geological surveys, neotectonic movements are clearly recorded, both on the pre-Quaternary and on the modern surface [46].

In general, the formation of productive sediments in the epicontinental sea is confirmed for the area, and the conditions of accumulation are equated to the conditions of sedimentation within the limits of a shallow marine shelf complicated by islands, bars, and overbanks.

It should be noted that this area underwent neotectonic movements and exaggeration during the ice ages, which led to the disruption of Paleogene sediments and the formation of numerous secondary amber deposits and large-scale halos of mechanical dispersion of grain amber. According to the data of search and search and evaluation works, the frequency of detection of amber grains in sand fractions within individual manifestations of this area varies from 9% to 31% (on average - 13,4%). Amber of psephytic dimensions of the Vilne deposit is confined to the intermountain world of the Oligocene [46].

Amber of psammite dimensions in the Quaternary, Neogene, and Oligocene Paleogene deposits, which lie above the deposits of the intermountain world, was formed as a result of redeposition of primary placers. In addition, this amber-bearing area, as well as the entire research area, is characterized by paleokarst, the formation of which in the post-Mezhyhirian period also contributed to the redistribution of primary amber deposits.

Primary amber placers of the Volodymyretsky district

Discovery of the Volodymyrets Shchydnyi deposit, located east of the village. Volodymyrets in the Rivne region, is the result of exploration and evaluation works carried out by RGE over the past

20 years within the boundaries of the Volodymyrets amber district. In addition to the deposit, promising manifestations of Dubivka, Zhovkini, Volodymyrets and Virka were discovered here.

Deposits of the productive stratum are mostly represented by sand fractions with different-grained material. Silt-sand and clay-sand intermontane formations are also found, mainly in the southern outskirts of the district.

The study of the Volodymyrets Shchydnyi deposit by means of wells, shafts, and an experimental trench made it possible to carry out detailed lithological studies of productive deposits and to analyze changes in their capacities and depths of occurrence.

Within the deposit, the roof of the Eocene era formations lies at hypsometric levels from 158,30 m to 164,70 m [46, 48] and reflects the morphostructure of the bottom of the sedimentation basin of the intermountain time. In general, it is an undulating surface with local depressions and elevations of various configurations and sizes. Fractionally weathered laterally and in sections, the material of the deposits of the Obukhov age (mica silty clays and argillaceous siltstones) indicates the relative deep water of the sedimentation basin and the calm hydrodynamic environment of their formation.

The sediments of the intermountain world, which lie according to the section above, were formed in the conditions of the shallow waters of the regressing epicontinental sea.

The stratum is composed of quartz, glauconite-containing, multi-grained sands, with a predominance of fine-medium-grained sands, containing an admixture of the coarse-grained fraction of the quartz composition, gravel grains and quartz pebbles, as well as pieces of amber. Usually, when amber is detected, a slight increase in the content of coarse-grained quartz grains and charred wood fragments is noted.

4. Definition of concepts of geotechnological methods of mineral extraction

In connection with the development and introduction of geotechnological methods of mineral extraction, there is a need to define new and clarify a number of concepts that are stable in mining science and relate to the subject of research. Formation and implementation of borehole hydraulic testing as a method of geotechnology for prospecting and trial exploitation of deposits was done for the first time by prof. V.Zh. Arensom, M.I. Babichev, E.I. Chernei [7, 51-54].

The existing terminology related to the concept of borehole hydraulic production is not indisputable. For example, B.Zh. Ahrens believes [7] that borehole hydraulic mining (HBM) is a method of underground mining of solid minerals, based on bringing the ore at the place of occurrence into a mobile state by means of hydromechanical influence and releasing it in the form of a hydraulic mixture to the surface. There is no objection to the disclosure of the essence of SGD as a method of underground mining, except for the term "...hydromechanical influence".

In our opinion, it should not be limited to hydromechanical influence, because the goal of geotechnology and its constituent parts of SGS is the influence of working agents on a useful mineral in the process of extraction to transfer it into a mobile state. There are systems that do not have a well (wells) as an element of the system. For example, removable cameras, which are reconnaissance products in the systems of mechano-hydraulic testing (MHO) and mechano-hydraulic production (MHD).

If we mean the entire complex of underground development activities without the presence of workers in the cleaning space under the SGS, such a definition does not reveal the essence of the name.

The method of deposit opening - wells, open and underground mining, as well as a combined option is a clearly expressed feature, which is especially important for the characterization of geotechnological mining methods, both in terms of form and content.

With regard to the mechanism of influence on the mineral, which is a means of transferring it into a mobile state, in our opinion, it is worth following the division into the term−working agent [51-54], which includes solid, liquid, gaseous substances and their combinations, and also mechanical action.

The term "hydro production" is acceptable at this stage, since the specific weight of energy water, which is supplied for destruction, erosion, disintegration, gravity hydraulic transport and other operations in the general energy balance, prevails compared to compressed air, surface-active substances, solid components, etc.

Taking into account the proposed classification feature and the expansion of the concept of a working agent, as a subject of influence on the mineral being developed, it is advisable to highlight the following methods of hydraulic extraction and give them a definition.

Borehole hydraulic production (SGD) is a method based on bringing a mineral at the place of occurrence into a mobile state by exposure to a working agent and releasing the hydraulic mixture to the surface through wells, which are productions of discovery.

Underground hydraulic extraction (UGD) is a method based on bringing a mineral at the place of occurrence into a mobile state by exposure to a working agent and releasing the hydraulic mixture to the surface through underground mining operations.

Combined hydromining (CMH) is a method that includes elements of HMD, underground and open-pit mining methods, based on bringing the mineral to a mobile state at the place of occurrence by the action of a working agent and releasing the hydraulic mixture to the surface through wells or underground mining.

Developing the research of Professor E.I. Cherneya, it is possible to give a new definition to the mechano-hydraulic product.

Mechano-hydraulic production (MHD) is a method based on bringing the mineral at the place of occurrence into a mobile state through the influence of a mechanical executive body and releasing the hydraulic mixture to the surface through vertical mining works that open the deposit.

Unlike wells, open pits are usually rectangular in cross-section.

Field testing is the most important element of exploration, and its results are one of the main components of field evaluation. According to V.M. Crater testing, which reveals the composition and properties of a mineral, is understood in a broad sense as a method that establishes the quality of mineral raw materials. Taking into account the proximity of hydraulic mining and hydraulic testing both in terms of the mechanism of impact on the mineral and in terms of the equipment used, as well as the logical connection between the principles of exploration and testing as a method, Professor E.I. Chernei singled out the following varieties [51-54].

Borehole hydraulic testing (SGO) is a method of implementing the principles of exploration, based on bringing the required volume of the investigated object at the place of occurrence into a mobile state by the influence of a working agent and releasing the hydraulic mixture to the surface through wells for further processing and testing.

Underground hydraulic testing (GWP) is a similar method, but with the release of a hydraulic mixture to the surface through underground workings for subsequent processing and testing.

Combined hydraulic testing (KHO) is a way of implementing the principles of exploration, which includes elements of SGO and PGO. It is also appropriate to highlight the method of hydro-hydraulic testing, as independent due to differences from SGO, PGO and KGO.

Mechanical-hydraulic testing (MHG) is a method of conducting geological exploration, based on bringing the required volume of the investigated object at the place of occurrence into a mobile state by the influence of a mechanical executive body and issuing a hydraulic mixture to the surface through vertical mine workings for further processing and testing.

Testing and development systems are a necessary component of the methods of MGO, SGO, PGO, KGO, MHD, SGD, PGD and KGD and their technologies.

Academician N.V. Melnikov defined the subject of mining as "a system of knowledge about the methods and means of searching, exploration, extraction and beneficiation of minerals." As an integral part of mining and its scientific foundations, this knowledge is subordinated to a single goal - the study of processes, phenomena, forms and their manifestations in nature, connections and regularities at the stages of exploration, trial exploitation and development of deposits.

Borrowing some technical and technological means in the study of the scientific foundations of MGO and MHD, the scientific and practical potential of related knowledge is used much more widely. Effective systems of testing and development of the proposed methods should be those that, due to the combination of qualitative and quantitative components, technical and technological parameters, allow obtaining a concentrate at the place of occurrence, leaving the containing rocks in the subsoil, which will be given later.

The state of study of the problem of amber extraction as a component of geotechnological methods of mineral extraction and their generalized classification

When analyzing and researching the works of scientists, it is known that the SGS method for various minerals is widely implemented in the mining industry of Ukraine, Russia, the USA, Canada, Poland, etc.

Starting from 1965, under the scientific guidance of Professor B.Zh. Apenca conducts scientific research and development work aimed at the implementation of the SGD of phosphorites in the Leningrad Region. In 1975, a semi-industrial site with a monthly productivity of 20,000 tons per unit was put into operation. Despite the well-known advantages of the method, the losses of the mineral in the targets exceed 50%.

At the stage of semi-industrial testing of equipment and development systems, research is being conducted under the leadership of B.S. Kovalenko in the conditions of the Lermontov Mining and Chemical Administration.

Research under the scientific guidance of Prof. D.P. Lobanova.

In some cases, it is technically impractical and economically unprofitable to use hydraulic mining. This primarily refers to the extraction of strong weakly fractured minerals. There are two extraction schemes:

- the rock is separated from the massif followed by the removal of the reflected rock mass by mechanical means and the rock mass is transported through the mine workings with the help of low-pressure (0,20-0,25 MPa) water;

- the rock is separated from the massif by a mechanical executive body with subsequent transportation of the reflected rock mass by hydraulic methods.

As a rule, the basis for using CGD technologies is the results of field exploration. The task is reduced to the clarification of individual mining and technological indicators on the basis of laboratory studies of the physical and mechanical properties of the mineral and overlying rocks. This is a significant drawback.

A fundamentally new approach is necessary - at the stages of exploration using the methods of MGO, SGO, PGO, KGO, move to trial operation, based on the results of which the effectiveness of geotechnological methods can be predicted and their use, in particular, MHD.

Structural elements of the considered methods are testing and development systems. In this regard, the classifications of underground mining methods, underground hydro-mining and gas extraction systems are known, which is the basis for creating a classification of systems.

The most complete information on this issue is given in the works of M.I. Agoshkova, R.V. Imenitova, Y.D. Shevyakova, N.I. Trushkova, E.I. Cherneya, V.P. Prokop'eva, G.A. Tsulukidze, G.N. Popova, Z.R. Malanchuk and others. [51-54].

There is no need to consider in detail the advantages and disadvantages of different classifications, because they are considered quite fully in various scientific works. Each of the developed classifications is based on the identification of contradictions in the existing ones and their resolution at a higher scientific and technical level.

S.M. Shorokhov, considering placer deposits with a small capacity and a positive deposit, considers the classification of academician L.D. Shevyakov most acceptable, and on this basis singles out two systems - columnar and continuous, i.e. systems of group "A" without division into layers.

A leap in the development of the mining industry in the 1970s was the scientific development of geotechnological methods such as borehole and underground hydraulic mining. In a relatively short period of time, these methods have passed all stages of scientific research and industrial development on deposits of various mineral raw materials - amber, diamonds, gold, etc.

N.O. Babichev and E.I. Chernei considered the classification of technological schemes of borehole hydraulic production and the selection of technology parameters and technical means at the design stages.

The classification proposed by Academic M.I. Agoshkov, is universal for ore deposits developed by traditional methods, can and should be the basis for systems of geotechnological methods, which is not disputed by researchers and is accepted as a classification - the standard of systems of MGO, SGO, KGO, PGO, MHD, SGD, PGD and KGD.

In the process of analyzing the methods and methods of amber extraction, the following classification of amber deposit testing and development systems can be proposed.

Testing methods:

1. mechano-hydraulic testing (MHO);
2. borehole hydraulic testing (SGO);
3. underground hydraulic testing (PGO);
4. combined hydraulic pressing (KGO).

Mining methods:

1. mechano-hydraulic mining (MHD);
2. borehole hydraulic production (SGD);
3. underground hydraulic production (PGD);
4. combined hydraulic mining (KHD).

Testing and development systems are the main elements of technology, which is the beginning of the design of geological exploration works and the functional activity of a mining enterprise [51-54].

Conclusion

A potential source of amber production can be exhausted deposits with off-balance reserves, which are man-made deposits, but this requires the development of a technological process.

Due to the imperfection of the existing technologies, losses of minerals in targets and dumps exceed 50%.

Existing technologies for extracting amber from sandy and sandy-clay rocks have a high energy intensity of rock destruction, and segregation requires improvement of technology and equipment to increase the efficiency of the final product extraction process and reduce energy, water and air consumption.

The proposed technological schemes do not provide for an ecological component, the possibility of mining waste reclamation, while their man-made nature requires additional research taking into account various mining and geological characteristics and host rocks and the development of recommendations for technology and equipment taking into account the ecological component.

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GEOMECHANICS INFLUENCE ON MINING BLOCKS IN SEISMICALLY ACTIVE AREAS AT MUFULIRA MINE DEEPS SECTION

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Abstract

Mufulira mine has been in operation since 1933. The mine is situated on the copperbelt region of Zambia. It is predominantly rich in copper and cobalt mineralization. Due to increase in mine depth that currently stands at 1,557m, the mine has been experiencing geomechanical challenges such as rock failures due to excessive stress changes around some mining blocks. This has necessitated changes in mining sequences to suit the present geomechanical conditions such as development of de-stressing cross-cuts between 62 and 64 blocks. Additionally, blocks have been subjected to shotcrete support method to prevent possible rockbursts/rock falls which can endanger safety of men working in these areas.

This study applied geotechnical investigation and geological field mapping methods to understand the Geomechanics mechanisms controlling the rock burst prone mining blocks at Mufulira mine. Damage mapping conducted in the footwall drives, cross-cuts and mining drives excavations indicate that there is a changing stress loading as one moves away from the retreating stope face to the east. The rockmass damage predominated by spalling process usually initiates from the northern top corner of the excavation drive.

1. Introduction

According to Suorineni F. T. (2013), geomechanics has proven to be the backbone of safe and cost effective mining practice. However, experience shows it still does not have the appreciation of most mines until there is a fatality or costly ore sterilization. This lack of understanding has affected the growth and maturity of the subject of rock mechanics, a key component of geomechanics. In rocks, free surfaces rarely exist until fracture occurs through breaking the cohesive bonding in the aggregate of minerals! Thus, the strength of rocks is NOT a simultaneous mobilization of cohesion and friction but successive destruction of cohesion followed by mobilization of the frictional strength due to the presence of free sur-faces following the destruction of cohesion.

Martin (1993) showed that in massive, hard, brittle strong rock masses, maximum friction and maximum cohesion are not mobilized simultaneously as Mohr Coulomb equation suggests. By the time friction is fully mobilized a significant portion of the cohesion has been lost (Fig. 1).

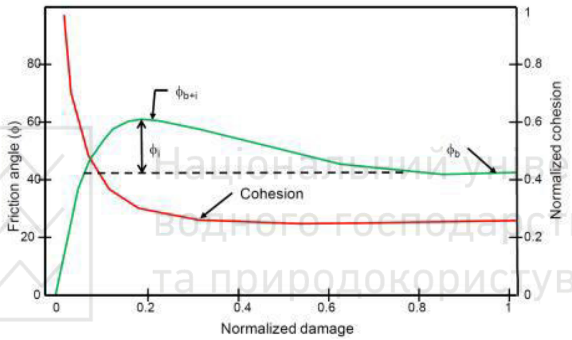

Fig. 1. Cohesion Loss-friction Mobilization (After Suorineni F. T., 2013)

$$\sigma'_1 - \sigma'_3 = \sigma_{ci}\sqrt{\frac{m\sigma'_3}{\sigma_{ci}} + s} \quad (1)$$

$$\sigma_1 - \sigma_3 = \frac{\sigma_{ci}}{3} \quad (2)$$

Where σ_1 and σ_3 are the induced major and minor principal stresses, and σ_{ci} is the uniaxial compressive strength of the intact rock. Equation (2) implies that massive strong brittle rocks friction plays have very little role in their failure. Note that Equation It should be noted that was equation (2) was based on tests and observations made on granite rock. Suorineni *et al*. (2009) showed that Equation (2) is rock-type de-pendent, and could be written as follows

$$\sigma_1 - \sigma_3 = A\sigma_{ci}, \quad (3)$$

where A is a rock type dependent parameter.

According to Ben-Guo *et al*. (2015), the mechanism of rock burst are due to strain relaxation of surrounding rock mass in newly excavated areas, and the dynamic response of rock mass to blast induced waves. Part of the strain energy stored in highly stressed zones is released in the form of shear movements along weak planes of discontinuities, while the other part of it is converted into kinetic energy, which eventually leads to rock expulsion from the surface of an excavation. Kaiser and Cai (2012) categorized rock burst damage in three classes: bulking due to fracturing, Ejection of rock due to seismic energy transfer, and rock fall induced by seismic vibration.

There are several methods of monitoring and identifying potential rock burst-prone zones. Research and industrial practice on the estimation and identification of rock burst-prone zones mainly focuses on theoretical analysis, laboratory test, numerical simulation and field measurement, as proposed by Fei *et al*. (2018). Field measurement includes the use of a micro-seismic monitoring system and field geological structural mapping.

This study applied geotechnical investigation, uniaxial compression tests and geological field mapping.

2. Mufulira mine DEEPS section-Case Study

2.1 Site Description

Mufulira mine is located in the Copperbelt province of Zambia in Mufulira town. The mine lies on latitude 12° 32' 22" South and longitude 28° 14' 10" East. The mine is one of the biggest underground mines in Zambia, and its major product is copper. The license area for Mufulira mine consists of Mufulira West Portal, Mufulira East Portal and the main Mufulira mine which comprises the upper, central and deeps section. This research is being conducted on the main Mufulira mine, deeps section. ploys Mechanized Continuous Retreat (MCR) mining method, which is a variant of sublevel open stoping. Fig. 2 shows a typical layout of Mechanized Continuous Retreat mining method. The method involves fan drilling of long holes from the roof of a sublevel. The sublevels are spaced at intervals of 17 m.

The layout of the mine consists of access crosscuts from the decline to the orebody. At the end of these access crosscuts, a footwall drive is developed, as illustrated in Fig. 2*d*. The footwall drive and the mining drive are linked by multiple orebody crosscuts, which are spaced at 50 m apart in the mining level (drilling level) as shown in Fig. 2*b*. However, at the drawing level, where blasted ore is collected from, as shown in Fig. 2*d*, the orebody crosscuts are spaced at 25 m apart. In terms of dimensions, the mining drive, footwall drive and crosscuts are all 4 m in height and 4 m in width.

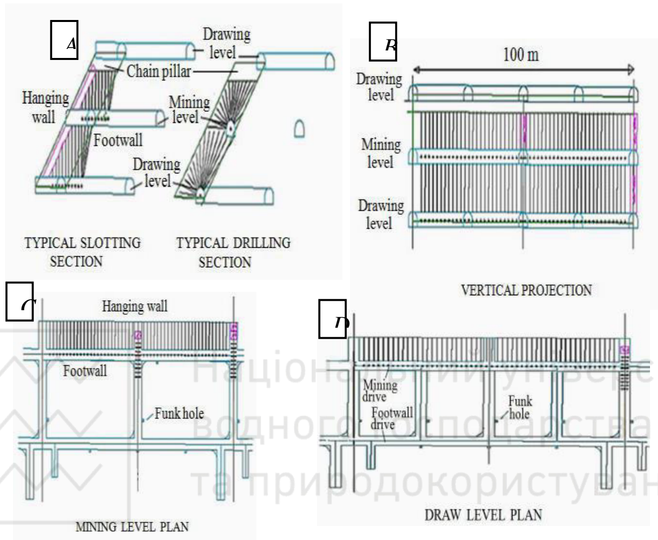

Fig. 2. Typical variant of MCR Mining method at Mufulira mine

If fan drilling is performed on two sublevels and the blasted ore is collected from the bottom sublevel, which is referred to as drawing level, then the method is known as Mechanized Continuous Retreat 2 (MCR2). If both fan drilling and ore collection are performed only on one sublevel, then the method is known as Mechanized Continuous Retreat 1 (MCR1). The design of the stope leaves a 3 m pillar at the roof as indicated in Fig. 3), which is known as the chain pillar. According to Immanuel and Mutambo (2016), the purpose of the chain pillar is to retain the broken hanging wall material from upper levels and thus prevents ore dilution to the blasted ore.

2.2. Geology of the rock burst prone mining blocks

The major geological units comprise a series of five different units. Stretching from south-west to north-east of Mufulira mine, these units are; basement complex, footwall quartzite, mineralized series, the hanging wall formation and finally the carbonate rocks. The mineralized series hosts three orebodies of Mufulira mine, *A*,*B* and *C* orebody.

Fig. 3. Showing Bornite(dark blue) & Chalcopyrite(yellow) mineralised C - Quartzite(C-Orebody) from 61P5 1523 mL; (A) Longitudinal 49 mm diameter core sample, (B) Cross-sectional view of the 49 mm core sample, (C) Thin section of the C-Orebody sample

The orebodies are bedded or of stratiform type (Brandit, 1962). Location of the rock burst prone area extends from 61 block up to 65 block, which ranges from footwall drives through cross-cuts and mining drives. All the three orebodies dip at an average angle of 45º. The footwall ranges in thickness from 0 to 5,0 m. Table 2 shows the general stratigraphy and geotechnical characteristics in Mufulira DEEPS section.

Table 2

General Stratigraphy and Geotechnical Characteristics in Deeper Mining Area

Geological unit	Thick	UCS (MPa)	RMR	General Geotechnical Description
Lower argillaceous quartzite	40 m	320		Good quality, massive, bedded partings infilled with Calcite.

A' orebody quartzite		220	81	Good quality, but bedded with weak graphitic partings in lower, grey, vacke part of orebody. Upper part shows calcite infilled bedding partings with beds 10 to 50 cm thick.
InterA/B quartzite		320	68	Average quality, Bedded
Banded shales, quartzite and dolomite		130-250		
Lower dolomite		50	49	Weak and friable
B' orebody quartzite	7 m	320	81	Very good quality, bedded.
Inter B/C quartzite	4-18 m	310	64	Good quality, bedded
Banded shales& dolomites		211		Moderate quality. Mud seam at base may be weak in places.
'C' orebody quartzite	9 m	310	81	Very good quality
quartzite	0-150 m	270	61	Shear zone at basement contact
Basement Schist		300		Strong competent
Basement Quartzite		300	go	Very strong competent

3. Materials and Methods

Geotechnical investigation, uniaxial compression tests and geological field mapping were undertaken in the seismically active zones in order to understand the geological characteristic of the rock type in the study area.

The Rock Mass Rating (RMR) parameter for orebody and hangingwall rocks was determined according to Laubscher's (1990) Geomechanics classification. RMR parameters were based on the measurement of discontinuity sets (number and spacing) as well as the character of the discontinuity. The RMR was then combined with the intact rock strength to give the overall Rockmass Strength Rating. Map3D

Boundary Element Method and examine 2D were used to model the tresses.

4. Results and Discussion

From the images, the C orebody quartzite showed coarse-grained (arkosic) sandstone severely disturbed and poorly sorted, with the ore forming minerals identified as chalcocite, chalcopyrite and Bornite. The footwall quartzite (Fig. 4) showed characteristics of granular to grained (arkosic) sandstone, which is poorly sorted with weak contacts that are metamorphosed.

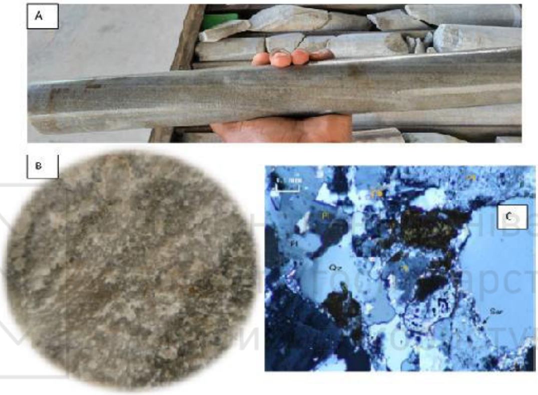

Fig. 4. Showing fresh footwall quartzite core sample from 61P5 1523 mL; (A) Longitudinal 49 mm diameter core sample, (B) Cross-sectional view of the 49 mm core sample, (C) Thin section of the footwall quartzite sample(*Qz*: Quartz, Pl: Plageoclase, Ser: Sericite, Cb: Carbonate mineral)

Some of the minerals observed in the footwall quartzite included quartz, orthoclase, plageoclase, spinel and granite. In both the orebody quartzite and footwall quartzite, sericite and anhydrite were identified as secondary minerals.

4.1 Geotechnical setting

4.1.1 Rock structure system

On the scale of the dimensions of the mine opening, the Mufulira mine rockmass is generally massive and strong. The rockmass exhibits a transition in the behaviour from brittle to ductile as one moves from the west to the east.

The eastern fringe is usually highly weathered and blocky in many places. In general the present geological discontinuities are moderately to highly persistent, with wide to very wide spacing. Discontinuity surfaces tend to be smooth to slightly rough on the scale of several centimetres and planar on the scale of several metres. Infillings are I rare within the orebodies, but can occur frequently in the footwall quartzites. Discontinuities are usually dry except for areas in the eastern fringe where water seepage along discontinuities can occur and iron staining is common. The footwall quartzite is characterised by beddings and cross-bedding planes. Bedding planes are the result of disturbances in the sedimentation process and are characteristic for all types of sedimentary rock, particularly mechanical sediments. These are very common on the east and towards the eastern fringe. Their interaction with other discontinuities under a high stress environment creates block instability around excavation openings.

Schistose occurrences are also occasionally present in the basement and footwall quartzite formations. Schistocity planes are typical in most metamorphic rocks. During metamorphism, mineral grains are rearranged resulting in a predominant mineral grain orientation due to rock pressure. Thus, weakness planes are generated especially if such planes are formed by mica or other lamellar minerals. Pressure release and/or tectonic activity can open such planes. As opposed to bedding planes, schistocity plane surfaces are mostly rough or undulating. If schistocity planes have opened throughout the metamorphic process, they are often filled with hydrothermal quartz and occasionally carbonates.

The field discontinuity survey on the levels from 1357 mL to 1457 mL were conducted. The results and analysis of the survey are presented below

The results of the geotechnical discontinuity survey reveal three (03) major discontinuities which create potential unstable wedges (Fig. 5) when exposed in the footwall drive or the crosscut excavation backs/walls. The geometrical and surface properties of the major discontinuities are presented in the Table 1.

Table 1

Geometrical and surface properties of the major discontinuities

Discon tinuity code	Dip (°)	Dip Directi on(°)	Persist ence	Spacing mm	Plana rity	Apert ure mm	Rough ness	Fill
J	43	023	3-10	60-200	P	0,1-0,25	R	Nil
J	72	283	3-10	200-600	P	0,1-0,25	R	Nil
J	40	271	3-10	200-600	P	0,1-0,25	S	Nil

Key;
Roughness; *R*-rough, *S*- smooth, *SL* - slicken-sided
Planarity; *P*-planar, *W*-wavy, *I*-irregular, *J*-Joint

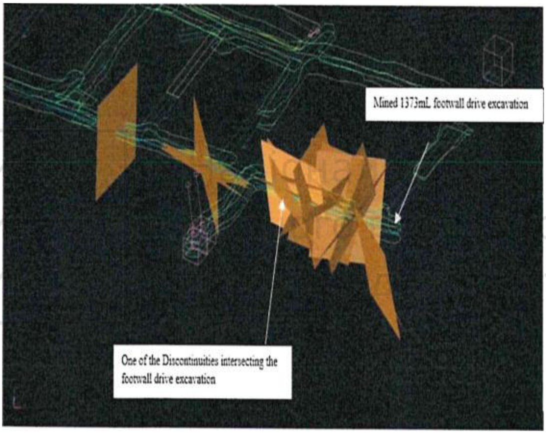

Fig. 5. Photo depicting 3D Surpac model of discontinuities intersecting the drive

4.1.2 Rock mass mechanical properties

According to the classification system used by the International Society for Rock Mechanics (ISRM - 1986 Rock Characterisation; Testing and Monitoring), the orebody quartzite are described as Extremely STRONG while the footwall and the hanging wall rocks are STRONG to Very STRONG.

The exception is the lower dolomite unit which forms the immediate hanging wall of the B orebody and is classified as Medium STRONG to STRONG. The approximate uniaxial compressive strengths and the Rock Mass Ratings (RMR) of the Mufulira mine rocks are given below; they were derived from point load tests.

The footwall quartzite in which most of the secondary development is placed, has a uniform strength except the eastern side of 64-Block where it is severely leached (a weathering effect) resulting in variable rock strengths between LOW to Very STRONG. The rockmass formation in the orebody between 60 and 64 blocks is strong and brittle.

This is the part of the mine were brittle fracturing and bulking dominates the rock mass failure process.

Violent rockmass failures mostly triggered by during primary stope blasting have been experienced in the 60 to 64 blocks orebody formation.

4.1.3 Rockmass rating and classification

The orebody rocks can be classified as Good to Very Good, the Lower dolomites as Fair and the footwall quartzite from 50 to 64 Blocks as marginally GOOD.

The occasional presence of joint planes in the footwall quartzite infilled with calcite or anhydrite combined with the unfavourable orientation of bedding planes with respect to footwall drives makes this unit particularly susceptible to wedge failures.

East of 64 Block is classified as Fair, locally and occasionally becoming poor where unfavourable discontinuity orientations occur in combination with wet, moderately weathered weak rock.

4.1. Mine Stress Regime

In 1976, the Mine at the time conducted some stress measurements. These 'premining' stress measurements were conducted on the 810 mL by overcoring six largediameter rosettes that were located around the circumference of a bored raise.

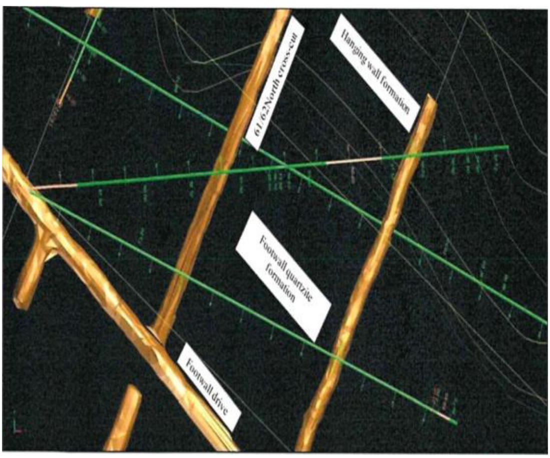

Fig. 6. Level plan on 1473 mL showing distribution of RMR along the drilled holes (Predominantly Good rockmass conditions)

Table 3

Laubscher's Rock Mass Strength (RMS) rating of the Mufulira rock formation

Rock type	Rock mass strength (RMS) MPa	Class
Footwall quartzite	112	Good
C-quartzite		GIV Good
Inter B-C	94	Good
B-quartzite		GIV Good
Lower dolomite	15	FAIR
Inter A-B	126	Good
A-quartzite	164	GIV Good

The measurements obtained showed that the principal stresses some 200 m down-dip of mining were as presented in Table 4.

Table 4

Magnitude and orientation of principal stresses from over-coring data results (Broome & Sandy, 1976)

	Magnitude	Orientation (dip/direction, degrees)
Sigma 1	37,1 MPa	72/345
Sigma 2	16,1 MPa	17/192
Sigma 3	11,6 MPa	

In 1984 and 1985, more stress measurements were taken by making use of five SCIRO cells. These cells were installed in the 50-51 drainage crosscut on 1032 m. Several problems were encountered, and as a result only one of the tests was successful. The major principal stresses for this test may be seen in the Table 5.

Table 5

Magnitude and orientation of principal stresses from SCIRO cells results (Broome & Sandy, 1987)

	Magnitude	Orientation (dip/direction, degrees)
Sigma 1	37,8 MPa	61/299
Sigma 2	34,1 MPa	17/176
Sigma 3	23,6 MPa	23/078

The orientation of both tests were plotted on a stereonet in order to assess and compare the results as shown in Fig. 7.

The ore extraction method employed at Mufulira mine (DEEPS section) is associated with high stope-induced abutment stresses. Generally the ore body dips at about 45 degrees and it is deduced from field observations of break-outs on the excavation boundaries that the major principal stress is oriented perpendicular to the dip of the ore body, whilst the minor and intermediate stresses are oriented along dip and strike of the ore body respectively.

Damage mapping conducted in the footwall drives, cross-cuts and mining drives excavations indicate that there is a changing stress loading as one moves away from the retreating stope face to the east.

The rockmass damage predominated by spalling process usually initiates from the northern top corner of the drive excavation, see Fig. 7.

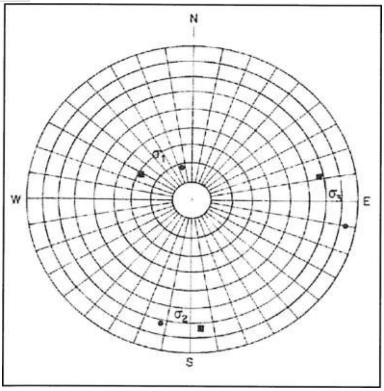

Fig. 7. Orientations of principle stresses obtained in 1976 (circles) and 1985 (squares), from Broome & Sandy, 1987 - showing good correlation between the two test results

As the location of the observed stress-induced damage is usually expected to be a function of the orientation of the major principal stress, it is deduced that the major principal stress is oriented perpendicular to the dip of the ore body, with the minor and intermediate principal stress oriented along dip and strike respectively. This to some extent verifies the results of the stress measurement conducted initially. The calibrated stress model constructed using Map3D Boundary Element Method software reproduces excavation model conditions that correlate very well with the observed/assumed conditions.

The model thus, is suitably used as a predictive tool to map out potential overstress zones. A 2D stress model using Examine-2D (Rocscience product) reproduced similar results, see Fig. 8.

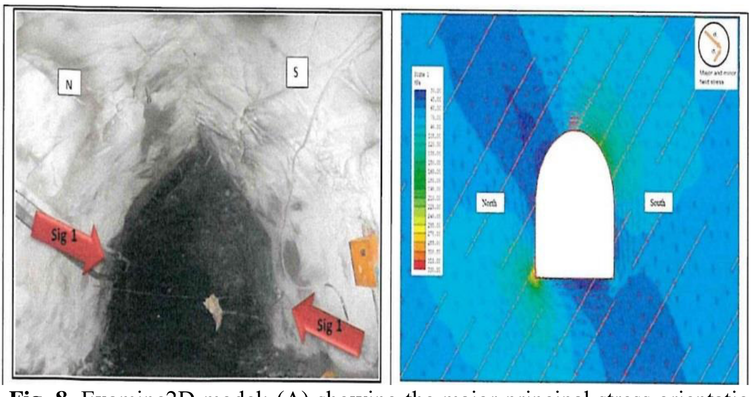

Fig. 8. Examine2D model; (A) showing the major principal stress orientation in Mufulira underground mine stress model and (B) showing stress results clip for induced stress field around the drive excavation

4.2. Rockmass condition in the affected blocks

Similar to the conditions in the existing cross-cuts, adverse ground conditions are anticipated at about 20 m before footwall contact of the C-orebody.

The targeted area for de-stress is located in extremely high stress environment with major principal stress exceeding 100 MPa in many places. Fig. 9 shows snapshots of Map3D display of major principal stress results contours.

The existing remains of the mining drive show that severe damage concentrated more on the southern side than the north and the roof.

This makes the method of holing into the void more practical as the fall-out depth into the roof does not exceed 3 m.

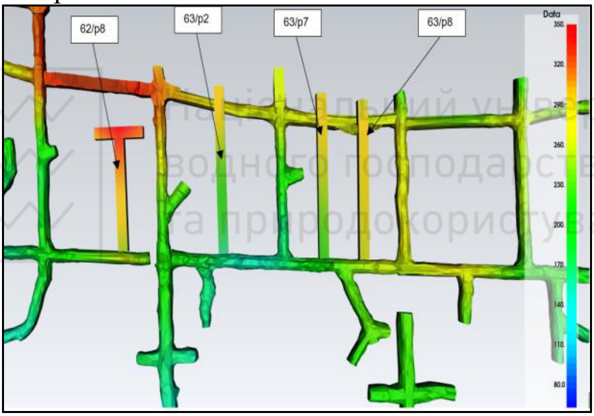

Fig. 9. Display of the tangential stress (cross-cuts will be mined from fair to adverse rockmass conditions – Tangential stress >250)

5. Conclusion

The orebody rocks in the DEEP section can be classified as Good to Very Good, the Lower dolomites as Fair and the footwall quartzite from 50 to 64 Blocks as marginally Good.

The occasional presence of joint planes in the footwall quartzite infilled with calcite or anhydrite combined with the unfavourable orientation of bedding planes with respect to footwall drives makes this unit particularly susceptible to wedge failures.

The ore extraction method employed at Mufulira mine (DEEPS section) is associated with high stope-induced abutment stresses.

Damage mapping conducted in the footwall drives, cross-cuts and mining drives excavations indicate that there is a changing stress loading as one moves away from the retreating stope face to the east.

The rockmass damage predominated by spalling process usually initiates from the northern top corner of the drive excavation.

Results of the simulation of the expected field stress conditions Map3D stress model indicates potential extensive damage in the 62P8 cross cut and drive and damage of the 63/p2 cross-cut after a few metres from the footwall drive. The conditions in 63/p7 and 63/p8 are expected to be fair (standard ground support) until about 30 m from the footwall drive.

Acknowledgement

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Potential Conflict.

There is no potential conflict associated with this study.

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SCIENCE AND PRACTICE FOR ASSESSING THE STATE OF UNDERGROUND STRUCTURES SUPPORT BY VIBROACOUSTIC METHOD

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Abstract

In this work, subject of the research is a method of non-destructive vibroacoustic control of underground structures support. The purpose of the research was to create a methodology and apparatus for vibroacoustic control of the state of the system "support – rock massif" with a wide range of use. The main types of objects where the use of this method is appropriate are determined. Negative influence of external factors on performance characteristics of support is shown. A basic type of support for underground objects is reinforced concrete. It is established that the most characteristic defects are formation of cavities in geological environment behind the support and broken connection of separate segments of the support. The influence of these defects on character of free oscillations of support elements at single shock action was studied theoretically. It is established that the following parameters can be informative for detecting these defects: amplitude characteristic of package of vibration, its duration and spectral composition. Information about the means of vibroacoustic control designed by the Institute with participation of the authors is provided. The methodical features of using vibroacoustic control for assessing technical state of different types of support are considered. The limitations for using the method are explained. Some results of the use of vibroacoustic control of support in underground objects of the various purposes are given.

Keywords: underground structure support, non-destructive control, vibroacoustic method, free oscillations, informative parameters, technical state

Introduction

In Ukraine, the use of underground space is developed in several directions. The first of them is related to mineral mining. The second direction consists in construction of underground structures for special purpose, for example, transport and hydro-technical tunnels, dock parts of the pumping stations, etc. The third direction is the alternative use of underground space for the objects that could be located on the earth surface. In particular, this applies to specific productions, for example, vine-making enterprises. This category also includes underground storage facilities, underground reservoirs for oil fuel. Accelerated development of building of objects exactly of this category is particularly important for Ukraine, taking into account a specific situation in the country. Underground construction, regardless of its functional purpose, is influenced by external geological environment. Support of underground structures is oriented on resistance to rock pressure. In some cases it must also provide waterproofing. The necessity to maintain operating state of the mine workings depends on their purpose and can last from a few months to many years. Other underground objects can assume long-time exploitation - for tens of years. Safe operation of workings is largely determined by technical state of their support required its periodic control. Traditional type of control is visual inspection with documenting of the detected defects. However, certain category of defects cannot be detected in this way. In particular, it applies to cavities in massif on the contact with the capital support. Their presence results in redistribution of stresses in the safety structure and causes its further deformation. In addition, cavities accumulate underground water and, in case of broken impermeability of the shell of the underground structure, become a source of filtration. The pressing task is to detect them timely with the use of methods of non-destructive control.

An effective modern method for detecting cavities behind the support is underground radar [1,2]. However, its use is associated with certain limitations:

- the need for direct access to the controlled surface;
- the impossibility to control rock massif when support with high electrical conductivity (concrete covered with a metal sheet, cast iron tubing, reinforced concrete with a large concentration of reinforcement) is used.

Other factors also play a certain role: significant cost of georadars and the need to attract highly qualified specialists.

There is also a problem that concerns support made of separate segments. Ideally, each of them should be able to withstand the load in accordance with the design solutions. Broken mechanical connection between the elements of support due to the destruction of the seams causes their uneven loading. Visual inspection detects only the consequences of underground structure operation in this mode - in the form of deformed elements. Timely obtained information on the distribution of stresses in the support makes it possible to significantly reduce the cost of preventive maintenance works.

The purpose of the research was to create a methodology and equipment for non-destructive control of the state of the system "support - rock massif" at objects with a wide scope of use. The benchmarks were: low cost of equipment and ease of use.

Analysis of other sources and the results of our own researches show that the goal can be achieved by using the vibroacoustic method [3-5]. The development of different variants of control is provided for the wide variety of possible objects, where support characteristics and control conditions differ significantly.

Theoretical justifications of variants of the method

A common cross-sectional shape of underground objects is a ring. An example can be vertical mine shafts, as well as some variants of horizontal and inclined hydro-technical tunnels. Support is mainly concrete or reinforced concrete. It is made in the form of separate sections, the seams between which are sealed. A fragment of the support in contact with the external environment is presented in Fig. 1.

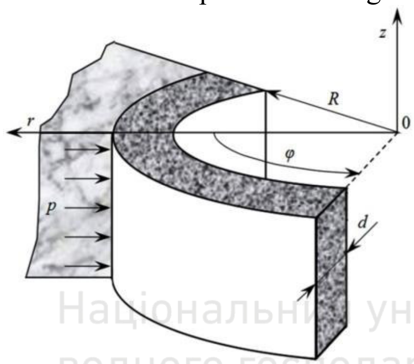

Fig. 1. Fragment of the ring support of the underground structure

The geometric characteristics of support are characterized by an internal radius *R* and thickness *d*. The hypothesis of a thin homogeneous shell is accepted. This is true if $d \ll R$. The second precondition is that the height of the section also significantly exceeds the thickness of the shell. This makes it possible to consider the problem in a flat formulation (in the cross-sectional plane).

The oscillations in the shell are excited by applying a point shock to it from the internal space of the structure. The interaction of the shock devices with the support material is considered absolutely elastic. Energy losses in the shell material associated with the viscosity of the material are not taken into account. The reaction of the environment to the radial deformations of the shell areas is represented by a uniform pressure *p*. To analyze the free oscillations in the shell, in addition to the geometric characteristics of the support, information on the physical and mechanical properties of the shell material and the environment is necessary. The list of characteristics and their symbols are given in Table. 1.

Table 1

Physical and mechanical characteristics of the elements of the mathematical model «support – environment»

Name of physical parameter	Dimension of parameter	Symbol of material	
		of support	of environment
Density	kg/m³	ρ_1	ρ_2
Modulus of elasticity in tension or compression	Pa	E_1	E_2
Shear modulus	Pa	G_1	G_2
Dynamic viscosity	Pa·s	η_1	η_2
Longitudinal wave speed	m/s	c_1	c_2
Dynamical Poisson's ratio	-	v_1	v_2

To analyze the behavior of ring-shaped structures under static or dynamic load, there is a special characteristic - cylindrical rigidity, denoted by the symbol D

$$D = \frac{E_1 d^3}{12(1 - v_1^2)}. \tag{1}$$

To simplify analytic expressions, an additional function Ψ is also introduced, which is associated with the current radial coordinate r and the angular coordinate of the φ in the cross-sectional plane. It is determined by a system of equations

$$r = \nabla^4 \Psi; \quad \varphi = E d \nabla^2 \Psi. \tag{2}$$

The key point is to take into account resistance of the external environment. This problem for cylindrical shells is described in detail in the works [6-8]. To understand the essence of physical processes, in our case, it is enough to accept simplified boundary conditions. The instantaneous resistance value p for a small area of the surface of the shell has three components:

- hydrostatic pressure at depth H

$$p_1 = -\rho_2 g H; \tag{3}$$

- elastic resistance from the environment

$$p_2 = -\frac{k_e \rho_2 c_2 \partial r}{\partial t}; \tag{4}$$

- viscous resistance from the environment

$$p_3 = -\frac{k_v \eta_2 \partial r}{\partial t}. \tag{5}$$

The k_e and k_v parameters in the formulas (4) and (5) are the proportionality coefficients.

Given that the shell is quite thin, and the main oscillation frequency is low, we can neglect the difference in the oscillation phases along the radial coordinate in the shell material. Then the instantaneous balance of stresses in the shell area caused by the shock is balanced by instantaneous resistance of the external environment

$$\frac{12}{d^2}(1-\nu_1^2)\nabla_k^2(\nabla_k^2\Psi)-\rho_1 d\frac{\partial^2 r}{\partial t^2}=\sum_{i=1}^{3}p_i \quad . \tag{6}$$

The total resistance of the external environment is defined as

$$\sum_{i=1}^{3}p_i=-\rho_2 gH-(k_e\rho_2 c_2++k_v\eta_2)\frac{\partial r}{\partial t} \quad . \tag{7}$$

Equation (6) describes several types of oscillations defined by the index k. In particular, the set of frequency components of radial displacement in the cross-sectional plane is described by the following equation

$$\Delta r_n(t)=\Delta r_0 e^{-\delta_n t}\cos(\omega_n t+\theta_n)+C, \tag{8}$$

where Δr_0 - initial deflection of the shell after shock; Δr_n - spectral components of the instantaneous deflection of the shell; δ_n – attenuation coefficient of spectral components; ω_n – circular frequencies of the spectrum components; θ_n – initial phase shifts; C – constant deformation caused by hydrostatic pressure.

The value of attenuation coefficient for the frequency component is determined by the equation

$$\delta_n=k_n(k_e\rho_2 c_2+k_v\eta_2). \tag{9}$$

where k_n are the coefficients of proportionality.

In most cases, the cavity is filled with a liquid mix of water with soil. This mix has a much lower density and viscosity than the natural massif. Accordingly, in the areas of the cavities, the attenuation coefficient for both individual spectral components and for a package of oscillations as a whole is significantly reduced. This means an increase in the duration of the oscillatory process and an increase in the average amplitude of oscillation.

Underground structures with a rectangular cross-section are also common. Their support is made mainly in the form of a set of reinforced concrete slabs, between which there are tight seams. The design condition of the plate assumes its strong mechanical connection with adjacent elements along the contour. One of the defects is the destruction of the seams. In addition to the possible filtration of water in the underground structure, it reduces the stability of support. The illustration to the mathematical model of support of reinforced concrete slabs is presented in Fig. 2.

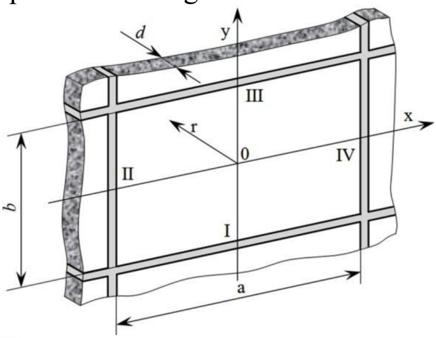

Fig. 2. Fragment of support with reinforced concrete slabs

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By analogy, let's consider the simplified model of occurrence of free oscillations in a thin plate. More detailed analysis of this process is shown in literature [9,10]. When impacting on the central part of the plate, there is a damped oscillating process, which is described by the equation

$$\frac{Ed^3}{12(1-\nu^2)}\left(\frac{\partial^4 r}{\partial x^4}+2\frac{\partial^2 r}{\partial x^2}\cdot\frac{\partial^2 r}{\partial y^2}+\frac{\partial^4 r}{\partial y^4}\right)=p. \qquad (10)$$

As in the previous case, the general solution of the equation (10) can be represented in the form (8) as a set of damped oscillations with different frequencies, and a constant component. The value of the basic frequency of oscillations and corresponding harmonics depends significantly on the boundary conditions. Two extreme idealized cases are considered for each side of the plate:

- prohibition of deformation in case of high quality seam;
- lack of stresses on the corresponding side of the plate when the seam is completely destroyed.

Four variants of clamping the sides of the plate are considered. Each of them has an expression to evaluate the value of the main cyclic frequency ω_1 of free oscillations. Due to the fact that the viscosity of the environment in contact with the plate is not taken into account, the assessment is just of qualitative nature. The results are given in Table 2.

Table 2

Calculation of indicative values of the basic frequency of free oscillations of the plate for different conditions of its fixing along the contour

Destroyed seam	Monolithic seam	The main frequency of free oscillations
-	I,II, III, IV	$\omega_1 = 11.18d\sqrt{\frac{E_1}{3\rho_1(1-\nu_1^2)}\left(\frac{1}{a^4}+\frac{0.605}{a^2b^2}+\frac{1}{b^4}\right)}$
I, II	III, IV	$\omega_1 = 7.71d\sqrt{\frac{E_1}{3\rho_1(1-\nu_1^2)}\left(\frac{1}{a^4}+\frac{1.115}{a^2b^2}+\frac{2.441}{b^4}\right)}$
II, IV	I, III	$\omega_1 = 4.98d\sqrt{\frac{E_1}{3\rho_1(1-\nu_1^2)}\left(\frac{1}{a^4}+\frac{2.566}{a^2b^2}+\frac{5.138}{b^4}\right)}$

According to the results of mathematical modeling, the tendency of reduced main frequency of the plate free oscillations is visible with deterioration of its mechanical contact with adjacent support elements. At shock excitation of area of support with a weak mechanical connection to adjacent elements and the surrounding massif, mechanical energy is largely localized in the volume of the slab itself. Due to this, duration of the oscillatory process increases and its integral amplitude characteristic increases. Increasing the stability of the plate is associated with an increase in energy outflow due to a qualitative mechanical connection with other elements on all surfaces except the internal. This drastically reduces the quality factor of the oscillatory system and causes a rapid decrease in the amplitude of all spectral components.

Technical means to implement the method

Serial technical means of vibroacoustic diagnostics are mostly passive recorders of vibration that occurs during continuous operation of mechanisms [11-14]. The method of spectral analysis is mainly used to identify and determine the nature of defects. Massive concrete and reinforced concrete structures can be diagnosed by the passive method only in some cases. In particular, this is possible, for example, when assessing the state of the bridge structures at the time of train movement [15]. The [16] describes the methodology and the results of the assessment of the state of building structures by determining the parameters of their vibration during the movement of urban transport. A similar approach is considered as one of the variants of vibroacoustic control of the state of concrete pavement [17]. In most cases, this technique cannot be applied for assessing the state of underground structures support.

Active vibroacoustic diagnosis involves forced excitation of the controlled object. Given the large mass of structures, their continuous excitation is energy expensive. However, it is sometimes used when using serial equipment for spectral signal analysis. The [18] describes the use of a perforator as an oscillation exciter.

Single shock excitation of structures is more widely used. The [19] describes the experience of inspecting of support in Japan tunnels with a hammer. In the simplest version, this assumes identifying the defects by ear by experienced operator. There is also information about modern control technologies: the use of a robotic complex with stable shocks, automated registration and signal processing using artificial intelligence technologies.

Studies of the authors [20] found that the most sensitive characteristic in the use of the vibroacoustic method is the amplitude of free oscillations. But at the same time, the value of this informative parameter is significantly influenced by the impact force and the conditions of contact of the vibration receiver with the surface of the structure. The problem of impact force is partially solved by the use of an accelerometer that is rigidly connected to the shock device. Numerical value of the informative parameter should be adjusted according to the magnitude of the output signal of the accelerometer. The disadvantage of this technical solution is the presence of an additional cable that connects the shock device to the electronic unit. The authors have developed a simple shock device where the residual impact energy is absorbed by a pre-compressed spring. The design of the device is presented in Fig. 3.

The massive metal case 1 is rigidly connected to the wooden handle 2 by retainer 3. Spring 4 and ball 5 are located in the cylindrical recess of the case 1. Their working position is fixed with a nut 6. The point of impact is the spherical surface of the ball. Thanks to the pre-compressed spring, with a low impact force, the design responds to contact with the surface as a whole.

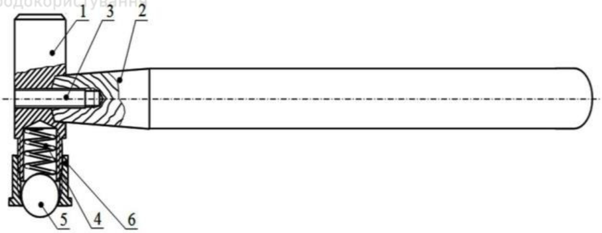

Fig. 3. Structure of the shock device: *1* – case; *2* – handle; *3* – retainer; *4* – spring; *5* – ball; *6* – nut

When the impact force exceeds the resistance of the compressed spring, it is compressed additionally, absorbing the excess energy of the impact. By selecting the value of the previous compression of the spring and training the operator, we managed to achieve quite stable parameters of the impact.

To increase stability of the contact receiver of the vibration, the following improvements were performed:

- a conical concentrator is used for point contact of the receiver with the control object;

- the performance of the device is ensured only when the pressure is achieved to the controlled surface)

The implementation of this technical solution is illustrated in Fig. 4.

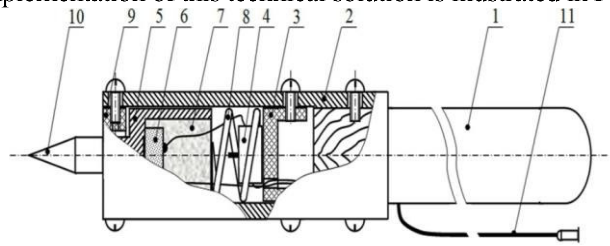

Fig. 4. Design of the contact receiver of the vibration of support: *1* – wooden rod; *2* – case; *3* – support; *4* – micro-switch; *5* – insert; *6* – piezoceramics; *7* - layer of compound; *8* – spring; *9* – cover; *10* – conical concentrator; *11* – cable with a connector

On the wooden rod *1*, there is a metal cylindrical case *2*, in which support *3* is rigidly fixed. It is installed with a micro-switch *4* with normally open contacts. Metal cylindrical insert *5* can limit its movement along the case *2* axis. In the deaf opening of the insert, there is a piezoceramics *6*, which is fixed with a layer of compound

7. There is a compression spring between the support *3* and the insert *4*. At the end of the case *2*, cover *9* is rigidly fixed.

The end of the insert *5* with a conical concentrator *10* passes through the hole in the cover. Cable 11 with a connection is designed for electrical connection of piezoceramic to electronic block.

In the non-working position, the insert *5* with the help of spring *8* is pressed against the cover *9*.

The contacts of the micro-switch *4* are open. The primary vibration converter in the form of piezoceramics is not connected to the input of the electronic block.

When conical concentrator presses on the controlled surface with the required force, spring *8* is compressed. This causes the closure of micro-switch *4* and provides electrical connection of piezocerams to the electronic unit. In some variants of the equipment, the power supply of the equipment is closed.

This significantly increases its efficiency. It is established that the minimum pressure required for establishing a stable acoustic contact of the sensor with a controlled surface is about 30 N.

One of the tasks of the research was to create the most simple and cheap means of control. From the point of view of hardware implementation, the simplest of the possible physical parameters is to determine the period of time [21].

The relevant informative parameter is the duration of the oscillation process damping to a threshold value. This principle is used in the work of equipment DYKON and SHVK [22] developed by the authors of this work. The exterior view of the electronic blocks of the mentioned means of control is presented in Fig. 5.

The threshold, which determines the end of oscillations analyzing, is fixed. Therefore, numerical value of the duration of the oscillation process, additionally to oscillation characteristics, depends on the initial amplitude as well. For its stabilization, the described devices for excitement and registration of oscillations were used. On the basis of the experience of these technical means operation, a more sophisticated vibroacoustic equipment of the KVAK was developed to control the state of anchorage and reinforced concrete support [23].

a *b*

Fig. 5. Means of vibroacoustic control with determining the duration of free oscillations: *a* – DYKON, *b* – SHVK

The informative parameter is the time of free oscillations relaxation. The choice of this parameter complicated the data processing process, but increased the reliability of the results. The value of relaxation time in a wide range of changes in the level of the input signal does not depend on its initial amplitude. The accuracy of the results is also increased by prompt statistical processing of data with multiple controls at one point. This provides automatic screening of the anomalous values for this sample and the statistical assessment of the accuracy of the result.

In addition to controlling the state of support elements, the assessment of the strength of the anchors is also monitored. The exterior view of the equipment with a set of peripheral devices is presented in Fig. 6.

a *b*

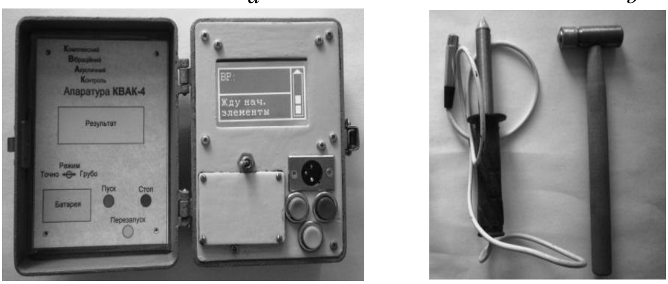

Fig. 6. Exterior view of equipment KVAK-4: *a* – electronic block, *b* – shock device and vibration receiver

The recent clear tendency is to create means for vibroacoustic control of building structures, including support elements, based on the spectral analysis of a package of damped vibrations [24,25]. The main advantage of this variant is weak dependence of control results on the level of the input signal and its high informativeness.

The classic variant of the modern approach is the conversion of the signal into a digital form and its subsequent processing by software tools. Designed with the participation of the authors, the equipment ISK refers to the previous generation, where the analysis of the spectrum of one signal is carried out by means of technical solutions. It is a ten-lane analog spectrum analyzer of parallel type with a range from 31,5 Hz to 16000 Hz [26]. The equipment is made in the flameproof design. This makes it possible to use it in coal mines that are hazardous by gas and dust.

The exterior view of the equipment ISK complete with peripheral elements is presented in Fig. 7.

a *b*

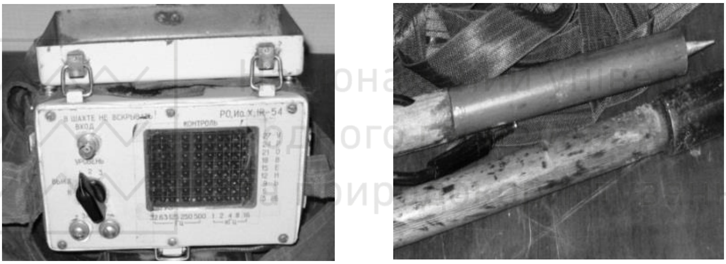

Fig. 7. Exterior view of equipment ISK: *a* - electronic block, *b* - shock device and vibration receiver

Methodical features of vibroacoustic control of support

The most convenient objects for vibroacoustic control are long underground structures with the same characteristics of support along the entire length. A favorable factor in controlling such structures is that there is no equipment and engineering communications. A typical example is some hydro-technical tunnels. The main part is usually fixed with reinforced concrete in the form of separate sections. Cross-sections for control are agreed with stakes. In their absence, the marking is made along the axis of the structure. The recommended step is 2 m. The control points in the cross-section are arranged with taking into account the position of the individual support sections. If possible, the points along the contour should be distributed evenly. The plots with variable thickness of the support are not controlled because they are characterized by other features of free oscillations. Control points are the points to apply mechanical shock. Examples of their placement are shown in Fig. 8.

Vibration reception points are located at a height which is much greater than the thickness of the shell. Three measurements should be taken at each point. The result is averaged.

Fig. 9 illustrates the performance of vibroacoustic diagnostics.

The peculiarity of vibroacoustic control, regardless of the choice of technical means, is the dependence of the informative parameter on the support characteristics.

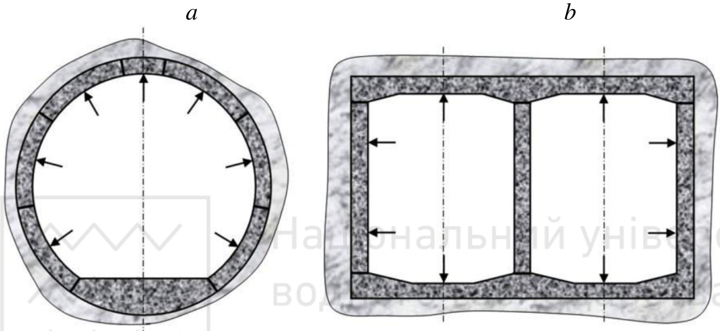

Fig. 8. Location of shock points in the cross-section of the support: *a* – in the underground part of the Dnipro-Ingulets channel, *b* – on the site of the sewer collector in the city of Dnipro

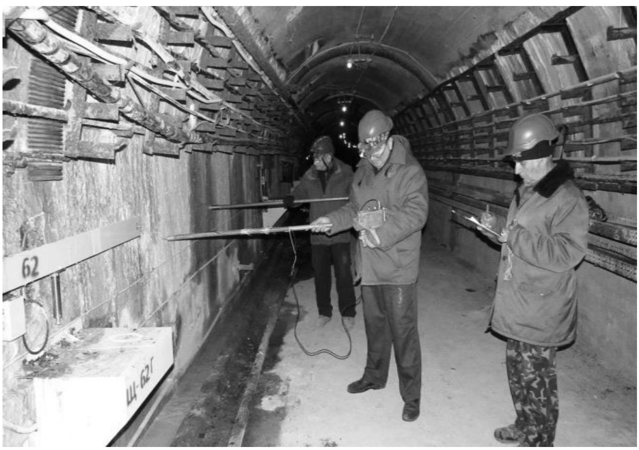

Fig. 9. Performing vibroacoustic diagnostics in the upper footway of Dnipro hydroelectric station

To determine of the technical state of the support elements of a certain size and shape, control is performed in areas where the state is established by direct methods such as control drilling.

The desired volume of samples in areas with quality and clearly defective support should satisfy the condition of the correct statistical processing (at least 30 definitions). The hypothesis of the normal nature of the distribution of values of the informative parameter in both samples with average p_n values for quality support and p_d for defective support is accepted.

The variation of values is determined by two factors: error of determining the informative parameter and features of a specific support point. If the presence of a defect causes an increase in the value of the informative parameter, then, according to the 3σ rule, the range from the minimum value to $p_n+3\sigma$ corresponds to the quality support.

Similarly, values exceeding p_d-3σ are suspicious for a defect. Possible distribution of values of the informative parameter is illustrated in Fig. 10.

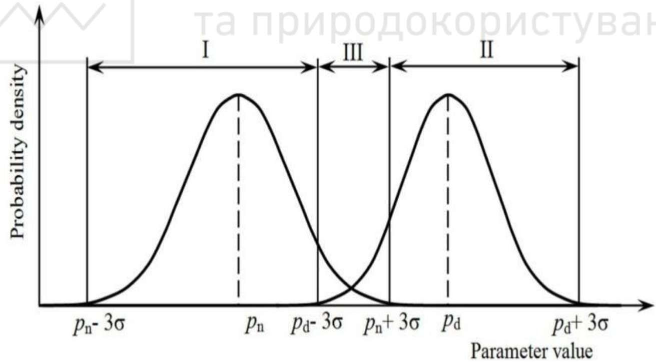

Fig. 10. Distribution of values of informative parameter in control of support of different quality

Regardless of the choice of informative parameter and means of control, its informativeness sharply decreases with the growth of the thickness of the shell (Fig. 11). In accordance with Fig. 11, three ranges of the thickness of the shell with different efficiency of vibroacoustic control are determined.

When the shell thickness is less than d_1, probability to detect defects is very high. In the thickness range from d_1 to d_2 , data distribution graphs for quality and defective supports are approaching. The width of the uncertainty zone becomes too large. With thickness values more than d_2, control becomes impossible at all.

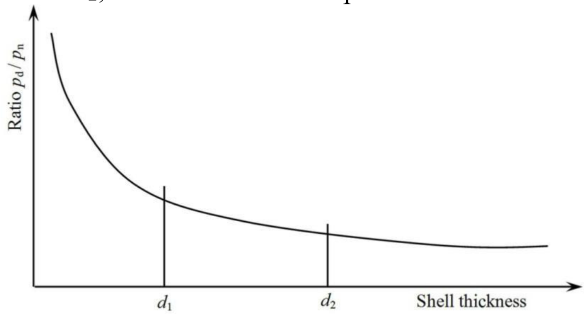

Fig. 11. Decrease of the information content of vibroacoustic control with an increase in the thickness of the shell

Practical experience showed the limit for the probability of detecting the cavity. It is a maximum support thickness 0.8–1.3 m depending on the type of support, variant of the method and characteristics of the equipment. The thickness of many reinforced concrete structures ranges from 0,5 m to 0,8 m, i.e. corresponds to the conditions of significant uncertainty of control results. In this case, the following measures are taken to increase the accuracy:

- to condense the control grid;
- to increase number of measurements at one point of control;
- to divide the obtained range of values by a certain number of gradations (from 6 to 10).

Then, by using automatic programs of isolines construction, the inner surface of the structure is scanned with displayed gradations. This map should be considered as a prognostic one, where areas of different probability of defects are shown with corresponding number of gradations. According to Fig. 11, for very thin shells, the informativeness of the vibroacoustic control is extremely high. An example of such a shell is a layer of shotcrete applied to the surface of the massif. The great difference in the value of the informative parameter for quality and defective areas of the coating allows establishing the presence of cavities behind the shell without preliminary calibration, and outlining them in details. This provides a special variant of the method, the scheme of which is presented in Fig. 12.

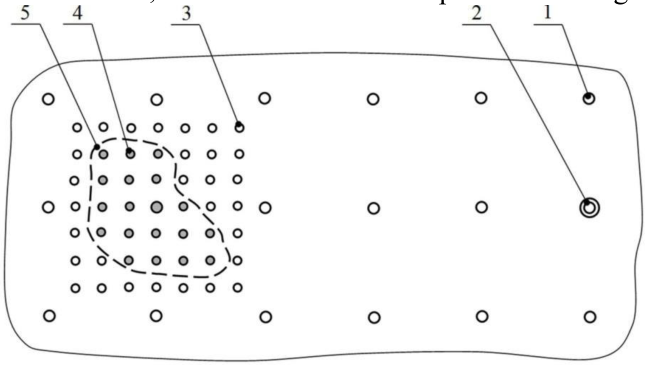

Fig. 12. The scheme of detection of the cavity under very thin shells: *1* – basic control points; *2* – point of reception of vibration; *3* – points with condensed grid of control; *4* – points with abnormal values of informative parameter; 5 – contour of the defective zone

Detection and control of a cavity is performed in two stages. The first performs control with the use of methods described earlier using points *1* of the base grid. If an anomalous value is found at one point, the vibration receiver is fixed at point *2* at such a height from it, which is several times greater than the step of control. The operator stimulates the vibration in the area of the potential cavity on the condensed grid in point *3*. Points *4* are singled out, the impact to which leads to anomalous values of the informative parameter. Due to the distant point of registration of vibration, the change in the distance between the excitation points and reception of vibration affects the result of the control much less than the difference between the contact of the shell with the adjacent environment. The defective area is determined directly at the site of the inspection without intermediate data processing.

Examples of the use of vibroacoustic control of underground structures support

An example of a long underground structure with reinforced concrete support is the sewer collector in the city of Dnipro. The cross-section of the collector is shown in Fig. 8b. The support is made in the form of reinforced concrete slabs with a thickness of 0.3 m.

Characteristic defects are cavities behind the shell and the destroyed seams between the plates (Fig. 13).

Fig. 13. The destroyed seams between individual slabs of support of sewer

The joint influence of both types of defects is reflected in the scan of the collector fragment (Fig. 14).

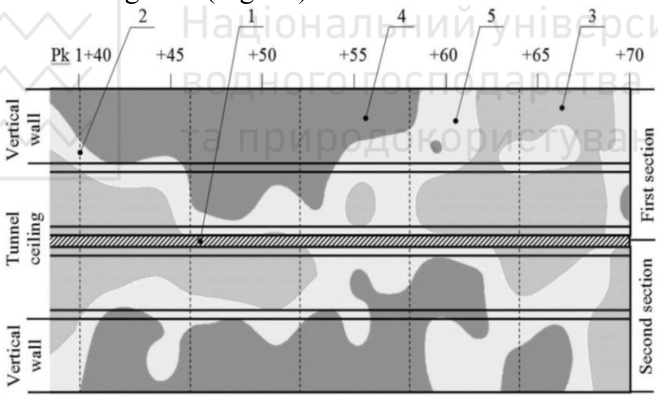

Fig. 14. A scan of a sewage collector fragment with the results of vibroacoustic diagnostics: *1* – the inner partition between sections; *2* – a seam between the mounting elements; *3* – areas with the absence of cavities behind shell; *4* – areas of the cavities behind shell; *5* – areas with intermediate state

The control of the bottom in this area was not carried out due to the presence of soil sediment on it. The drawing shows that the cavities are of considerable size and concentrated in the soil thickness, mainly behind the extreme vertical walls of the structure.

The vibroacoustic diagnosis of the underground part of the Dnipro-Ingulets channel was also performed. The channel consists of two parallel tunnels, the cross-section of which is presented in Fig. 8a. The thickness of the curly reinforced concrete blocks that create the tunnel shell is 0.45 m. The internal radius of the tunnel is 2.4 m. Deterioration of conditions for the inspection and the increase in the thickness of the shell caused a significant expansion of the uncertainty range of the support technical state. After computer processing of the primary data, a picture of probable cavities behind the shell was created. Its fragment is shown in Fig. 15. The most likely position of the cavity is shown by the arrow.

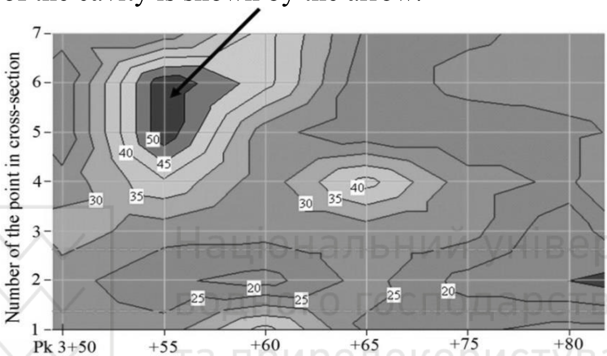

Fig. 15. A scan of fragment of tunnel № 1 of underground part of the Dnipro-Ingulets channel with vibroacoustic diagnosis results

In pressure culvert of hydroelectric station used a two-layer shell. The main layer is a monolithic reinforced concrete. The inner part of the water duct is lined with a metal sheet, the thickness of which reaches 20 mm. In case of poor contact of the metal sheet with the main concrete layer, even a strong metal shell is destroyed due to the processes of cavitation. Therefore, it is very important to identify potentially dangerous areas and take timely measures to eliminate cavities.

In the objects of this type effective is an inspection scheme with a stationary remote vibration receiver and a dense grid. Defective zones are displayed directly in the diagnostic process (Fig. 16).

A simple and effective method of strengthening the cracked contour of workings in ore mines is the applying of shotcrete. The main requirement for this type of support is a reliable adhesion of the applied layer with rocks. Vibroacoustic method is also used for operational non-destructive control of the coating quality. The thickness of the layer applied at a time does not exceed 50 mm. It can be considered as a very thin shell, and the results are displayed directly at the inspection site.

Fig. 16. The determination of the areas of poor contact of the metal to the reinforced concrete in the chamber of the working wheel of the hydraulic unit No. 12 of the hydroelectric power station in Kremenchug

The method of assessing the quality of the coating is illustrated in Fig. 17*a*. An example of detected areas of delamination is shown in Fig. 17*b*.

Fig. 17. Non-destructive control of quality application of shotcrete in the main workings of iron mine: *a* – the process of performing control, *b* – detected areas of delamination of shotcrete

Conclusions

The work shows the need to use non-destructive control methods for assessing technical state of underground structures support. A number of possible variants of control are analyzed.

The expediency of the use of the vibroacoustic method for detecting cavities in the geological environment at contact with the support and at weakening of mechanical contact of the support elements with each other is theoretically substantiated.

The choice of informative control parameters is also substantiated. The information on the development of the means for vibroacoustic control, which are designed by the Institute of Geotechnical Mechanics of the NAS of Ukraine, is provided. The methodological features of vibroacoustic control for different types of support are considered.

Examples of practical implementation of methodological provisions for different types of underground objects are given.

Acknowledgements

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DETERMINATION OF DUCT PARAMETERS FOR AUXILIARY VENTILATION IN QUANG NINH UNDERGROUND MINE

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Abstract

Ventilation when driving roadways is one of the most important considerations in coal underground mines. Ventilation efficiency depends on fan performance and ventilation ducting system. In recent years in Vietnam, ducts have often been produced domestically. However, parameters of the duct as duct leakage, duct resistance for designing auxiliary ventilation system are referenced from abroad handbook. This lead to inaccurate design results and needs to adjust efficiency of auxiliary ventilation during driving roadways. Determination of duct resistance; air leakage in ducting system have been undertaken. The research result has been used to optimize the auxiliary ventilation system.

Keywords: air leakage, auxiliary ventilation, duct resistance.

Introduction

In each country, ducts are manufactured from different materials and technologies, so the resistance coefficient and air leakage of the ducts are not the same. Studies on duct resistance and air leakage began to be carried out in the middle of last century. In recent years, the number of these works is not much, while the material quality of the duct is higher than before.

In developed mining countries such as Russia, Ukraine, Germany, Poland, The United Kingdom. The United States, Japan, etc. ... since the middle of the last century, they have carried out research on duct parameters. The results of these studies can refer to the works of scientists from some countries with a traditional background in mining, such as institutes, universities. Among the typical scientists, the scientists in former Soviet Union can mention such as: A.T. Ayruni, A.S. Buchakov, A.A Bobrov, A.B. Braitsev, I.I. Medvedev, S.V Yanko, S. Tkachuk, L.F. Bazhenov, V.E. Eliseev, V.B. Komarov A.A. Eremenko, V.I. Golinko, I.I. Lebedev, L.A. Puchkov, O.A. Mukha, P.I. Mustel and K.Z. Ushakov.

In Australia, scientists Barret and Wallman, Jones and Rodgers determined the frictional resistance and air leakage for duct different materials. British scientist Vutukuri has proposed to solve the air leakage problem by assuming a number of discrete leakage paths and treating the leaky duct as a ventilation network.

Scientists D.A. Telyakovsky, V. Komarov pointed out that if the effects of aerodynamic factors on air leakage are not fully taken into account, the results of air leakage level are determined almost higher than in reality.

Contrary to the results of the studies in the former Soviet Union countries, in the United States, according to survey of Mine Ventilation Services Inc. the friction coefficients referenced from textbooks and documents are larger than that measured at the field under the same conditions. This problem can be explained as follows: these data were published decades ago while at present, materials, as well as duct technology are much different.

In Vietnam, studies on an auxiliary ventilation mainly aimed at finding solutions to improve the ventilation efficiency when mining roadways driven in coal mines. The number of these works is not much, especially there is no research on the resistance and air leakage in ducting system being used in coal mines.

In the past, due to flexible ducts were often imported from abroad, parameters of the duct as duct leakage, duct resistance were referenced from abroad handbook to design the auxiliary ventilation system. However, currently, flexible ducts have often been produced domestically, determination of a relationship of the duct leakage and the duct aerodynamic characteristic must been undertaken.

1. Literature review on the air leakage and resistance of ducting system

1.2. Literature review on determination of duct resistance

Moving the air in the ducting system often result in loss of certain energy (pressure). There are two types of resistance: friction resistance and local resistance. For the ducting system kept tight, straight during experimental procedures, the energy loss on the ductwork is caused by frictional resistance.

In mine ventilation, characteristic quantities for frictional resistance are:

r - specific resistance per unit duct length, (km/m);

α - Friction factor, KgF s^2/m^4;

λ - Friction coefficient, dimensionless; λ=65,4α

The values for published values of the friction factors by authours as shown in Table 1.1.

Table 1.1

Quoted friction factors α for flexible duct

No	Friction Factor α, KgF, s^2/m^4	Reference
1	0,00054 0,00046- 0,00048	Telyakovsky and Komarov, 1969 Burtrakov and Ushakov
2	0,00030	Le Roux, 1979
3	0,00037- 0,00046	Hartman and Mutmanski, 1982
4	0,00051	Baret and Wallman, 1983
5	0,00023	Jones and Rodgers, 1983
6	0,00038	Vutukuri V., 1983

G.V. Levin show the resistance per 100 m of duct as in table 1.2

Table 1.2

The resistance per 100 m of duct, (kμ)

D, mm / Type of duct	300	400	500	600	700	800	900	1000
M	128	31,0	10,0	4,0	1,8	0,9	0,5	0,3
Tekctovinnite	56	10,8	3,3	1,2	0,5	0,25	0,13	0,08

However, G.V. Levin noted that the resistance value are as in the table 1.2 when ducting system was installed well. If ducting system was not installed tight, straight these values could increase more 25%.

1.3. Methods of determination of duct air leakage

Experimental method

Experimental methods are mainly performed on the model with the ducts and fans used in field.

Semi-experimental method

Dzidziguri and Cholikidze (1977) proposed a method for the summation of discrete leakage paths for calculating the total air losses in long air ducts. Assuming that air leakage in the first l meters of a duct is ΔQ m^3/s, and the initial quantity of air beyond the fan is Q_0 m^3/s, then a leakage coefficient can be described as $\delta=(\Delta Q/Q_0)\times 100$, (%). Summing the air leakages over the entire duct and simplifying, an equation for the total air losses over the entire duct length is given by

$$\sum \Delta Q_n = n.\delta.\frac{Q_o}{100}\left\{\begin{array}{l} 1-\dfrac{\delta.(n-1)}{100.2!}+\dfrac{\delta^2.(n-1)(n-2)}{100^2.3!} \\ -\dfrac{\delta^3.(n-1)(n-2)(n-3)}{100^3.4!}+\cdots \end{array}\right\}.$$

Sufficient accuracy can be obtain by considering only the first five to six terms, and for low values of δ (0,4-1,0%) three terms are sufficient.

From the above equation, the air leakage coefficient - p, the efficiency of the air delivery of duct length L-η can be obtained by the following equations

$$p = Q_q/\left(Q_q - \Delta Q_n\right) \text{ and } \eta = 1/p.$$

Vutukuri Mathematical Solutions

Vutukuri (1983) proposed that analysing flow in a leaky duct is possible by assuming a number of discrete leakage paths and treating the leaky duct as a ventilation network. In Fig. 1, air enters the duct and leaves either through leaky joints or via the exit of the ducting.

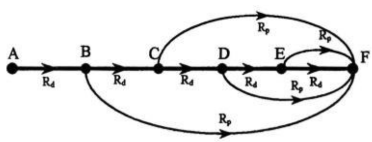

Fig. 1.1. Vutukuri's network analysis for leaky duc

A number of assumptions have been made as: Leakage paths have some resistance and the resistance coefficient of leakage paths (R_p) is the same.

- The resistance coefficients of all duct sections are the same R_d.
- The pressure outside the duct is assumed to be the same along the airway.

So that: Q_{BF}=Q_{AB}-Q_{BC} and because these are in parallel

$$R_{BF} \cdot Q_{BF}^2 = R_{BC} \cdot Q_{BC}^2 .$$

From that the leakage from *B* to *F* can be found. Vutukuri found that the air leakage depends on flow rate, the length and the diameter of duct.

Some researchers gave the results of the air leakage coefficient in the form of tables or graphs for certain types of duct.

1.4. Literature review on results of the air leakage coefficient

The results of the air leakage coefficient shown in the form of tables or graphs for certain types of duct are as:

V. Komarov and D. Telyakovsky gave the results of the air leakage of the duct per 100 m of the ducting system. According to G.V. Levin, the air leakage coefficient p of the flexible duct with length *L*(m), when ducting system installed well, have values as shown in Table 1.3.

Table 1.3

Coefficient and percent of air leakage of flexible duct M

Duct length, m	200	400	600	700	800	1000
Air leakage coefficient,	1,21	1,33	1,45	1,50	1,54	1,64
Percent of air leakage , %	17,4	24,8	31,0	33,3	35,1	39,0

If using TV synthetic flexible (tektovinnite) duct, the air delivery efficiency increases and the air leakage decreases quite significantly (Table 1.4).

Table 1.4

Air delivery efficiency η and air leakage p of flexible duct TV (tektovinnite)

Diameter (m)	Coefficient	Duct length, *L* (m)							
		100	200	300	400	500	600	700	800
0,5	η	0,98	0,95	0,91	0,87	0,83	0,77	0,72	0,70
	p	1,020	1,053	1,099	1,149	1,205	1,299	1,389	1,429
0,6	η	0,8	0,97	0,93	0,90	0,87	0,84	0,79	0,76
	p	1,020	1,031	1,075	1,111	1,149	1,190	1,266	1,316
0,7	η	0,99	0,97	0,95	0,92	0,90	0,87	0,84	0,79
	p	1,010	1,031	1,053	1,087	1,111	1,149	1,190	1,266
0,8	η	0,99	0,98	0,96	0,94	0,92	0,90	0,87	0,84
	p	1,010	1,020	1,042	1,064	1,087	1,111	1,149	1,190

Formula of determination of duct air delivery efficiency

The research work of K.Z. Usakov show that for flexible ducts, air leakage per a section is approximately 1% (with the first 20 duct sections); each subsequent section is equal to 0,5%. Therefore, air delivery efficiency can be calculated by the following expressions

For duct length $L \leq 20$l

$$\eta = \frac{1}{1+0{,}01\cdot n}\,.$$

*For duct length L>*20l

$$\eta = \frac{101}{1+0{,}05\cdot L}\,.$$

where L total length of ducting system; n: number of ducts; l:length of a duct.

According to the authours F.A. Kozhanov, I.S. Rodkin, air leakage coefficient is determined by the formula

$$p = 1+\frac{f}{3}L-\frac{5f^2}{6}L^2\,,$$

where

$$f = \sqrt[3]{\frac{tk^2}{2}}\,v\dot{a}k = k_y\,\frac{D_{\dot{o}}}{L}\,,$$

k - Specific coefficient of air leakage (level of air leakage per 1 m when pressure 1 kG/s^2);

k_y - Local coefficient of air leakage;

$D_{\hat{o}}$ - Duct diameter.

However, the above formulas did not take into account the influence of factors such as air flow, duct diameter.

Authour Bogomolov (Ukraine) shown that, air leakage flow through the joints connecting duct depends linearly on static pressure loss: $\Delta Q=B\cdot H$ (m^3/s);

where B: Constant was determined experimently for each duct type;

H - Static pressure loss, mm H_2O.

Analyses the literature, the findings suggest that:

The resistance and air leakage of duct the usually are determined by experimental methods.

The values of the resistance and air leakage of ducts have different due to different technology and materials made duct. At present materials, as well as duct technologies are much different from before, therefore determination of air leakage and resistance of auxiliary ventilation ducting must be updated. In Vietnam, ducts are now produced by higher quality materials than previously imported ducts.

Literature review on duct parameters, some researchers often showed results of air leakage and resistance of duct in the form of tables or graphs for certain types of duct. Some analytical expressions given are unreliable and do not took into account the relationship between the duct parameters.

The determination of the duct resistance is carried out by the experimental method through the duct diameter, head loss and flow rate on the test duct. The level of air leakage is estimated from the relationship between the geometrical and aerodynamic parameters of the duct.

2. Fundamental basis of determining resistance and air leakage of the duct in Quang ninh coal mine

2.1. Fundamentals of airflow

Moving the air in the ducting system often result in loss of certain energy (pressure). Pressure loss is due to as follows:

- Pressure loss is due to overcome viscosity of the air moving in a straight duct and a constant cross-section. It is the energy loss due to friction resistance and is proportional to the duct length and diameter.

- Pressure loss is due to overcome local resistance, as well as deformation of duct. This energy loss depends on the directions and values of airflow velocity.

In practice, air leakage through in ducting system flows in turbulent flow mode. In turbulent flow mode, airflow energy loss for overcoming viscosity of the air due to turbulent vibrations. Pressure loss due to frictional resistance in a round duct is determined by

$$\Delta P = H = \lambda \frac{L}{D} P_v, \qquad \text{Or} \quad \frac{\Delta P \cdot D}{P_v L},$$

where

ΔP - Pressure loss (head loss) due to frictional resistance in duct L long, mm H_2O;

P_v - Velocity pressure in duct, mm H_2O;

λ - Friction coefficient, dimensionless coefficient;

L - Distance between two cross sections of duct, m;

D - Diameter of the duct, m;

However, at present, there is no expression for calculating friction coefficient in turbulent flow mode. It has been determined experimentally.

Theoretically, for the short ductwork, the static pressure loss between the two cross-sections of duct is negligible, so the total pressure loss can be considered to be the velocity pressure loss.

In laminar flow mode, coefficient λ is usually higher than turbulence mode (due to small airflow velocity) and depends linearly on airflow velocity approximately,

2.2. Factors affecting on resistance and air leakage of duct

Currently, many studies have been showed the results of air leakage and resistance of the duct depending mainly on the length, materials and diameter of the duct. The results of these parameters are often presented in the form of tables or graphs. Thesis will focus on factors that mainly affect duct leakage and from that derive analytical expressions to calculate air leakage coefficient based on these factors.

Ducts of different sizes and diameters

Air leakage of the ducting system is affected by the length of duct. Obviously, when the duct length is longer, the ducting system requires more joints. For flexible ducting system, air leakage through these joints cannot be avoided. The degree of the air leakage in the ducting system depends on duct diameter; if the duct diameter - D is larger, the degree of the leakage is smaller due to the resistance of the duct that is inversely proportional to D^5.

Aerodynamic parameters

Air volume is one of the important factors to consider when estimating air leakage through ducting system into the face. Regarding the pressure in the duct, studies on the level of airflow to the face give the following remarks: the variability of the pressure values inside ducting system is not much that influences air leakage level about 1-2%.

Duct system resistance

Duct system resistance affects the degree of air leakage when the joints are of poor quality, but in the case of good installation practices, local duct resistance in ductwork has small.

The resistance and air leakage of duct depend on working life, installation and maintenance of ducting system.

2.3. The duct used in underground

Auxiliary ventilation systems in underground used is the force system, in which the fresh air is led to the face through the duct. Flexible ducts and different types of fans are used for the auxiliary ventilation system. There are various types of ducts: rigid, semi-rigid and flexible. Depending on the different types of duct, there are different advantages and disadvantages.

In practice, in Quang Ninh mines, PVC coated fabric duct is suitable for high power fan in order to reduce level of the air leakage and increase durability of the ducting system, especially at site where a duct connects to the fan.

2.4. The basis for determining duct resistance

A relationship between pressure loss and flow velocity in the duct is given by

$$\frac{P_1 - P_2}{L} = \frac{\lambda}{D} \cdot \frac{\rho}{2} v^2,$$

where

P_1 - Pressure of air at section 1;

P_2 - Pressure of air at section 2;

ρ - Air density, kg/m^3;

V - Average velocity at the duct cross-section, m/s.

In laminar flow mode, friction coefficient depends on Reynolds number and smoothness of the duct material. Duct resistance coefficient can be determined by A.D. Altsul's formula

$$\lambda = 0{,}11 \cdot \sqrt[4]{68/\mathrm{Re} + k/D}\ ,$$

where k - Roughness of the duct wall material;

However, using this formula could be difficulties to take into account roughness of the duct wall material.

In turbulent flow mode, there is currently no analytical formula for calculating the coefficient λ. A relationship between λ and Re is often determined experimentally.

2.5. Theory of leaky duct

When air flow is moved in ducting system, air leakage is always presented. Air leakage is a complicated aerodynamic phenomenon. If there is not air leakage through the duct, the pressure of the fan generated and the air flow throughout the ducting system can be described by a model quite accurately.

Air leakage can be described in the following two physical models:

+ Discrete - air leakage leaks through joints of ductwork

+ ontinuous - randomly distributed outlets along the ductwork walls.

According to Goodfellow, H.D. Tähti, the process of movement of the airflow in the duct is described by the conservation equation of energy and mass usually solved with the following conditions:

- The air flow in the duct is turbulence flow;
- The density of the air is a constant;
- Local resistance can be calculated as the additional factor to frictional resistance.

The authour B.I. Medvedev show that air leakage occurs along the ducting system. Depending on the leakage flow, the air permeability through the wall of the duct will be turbulent flow (if the leakage is large) or laminar flow (if the leakage is small). The authours A.A. Myasnikov, I.A. Kamyshansky investigated that: the variability of the pressure values inside flexible ducting system is not much that influences air leakage level about 1-2%. From Experimental results, authours I.A. Shvyrkov, F.S. Klebanov show that at the end of ducting system, flow rate, as well as the pressure decreases while level of air leakage through the ducting system decreases quite significantly.

The authour Sh.P. Khangeldyan pointed out that, if the ducting system is installed straight, the local resistance can be calculated as the additional factor with frictional resistance.

In conclusion:

Auxiliary ventilation systems in coal underground mine used is the force system, in which the fresh air is led to the face through the duct. Flexible ducts produced by different materials with diameter of 0,5-1,0 m are often used. Duct is available in various lengths, generally in 10-20 m lengths. At present, flexible ducts manufactured by Vinacomin - Cam Pha Materials Trading JSC are one-sided or double-sided PVC coated duct. These ducts have a smaller resistance and a longer working life than fabric ducts produced before.

In laminar flow mode, duct resistance coefficient can be determined by the A.D. Altsul formula. However, using this formula could be difficulties to take into account roughness of the duct wall material.

Air through in ducting system in turbulent flow mode, the expression for determining Atkinson's resistance as $H=RQ^2$ (also called Square Law because the pressure drop is proportional to the square of the volume of airflow rate). In turbulent flow mode, duct resistance coefficient has to be determined experimentally.

3. Determination of duct resistance coefficient

3.1. Fundamentals of duct resistance

Air leakage through in ducting system flows in turbulent flow mode. In turbulent flow mode, airflow energy loss for overcoming viscosity of the air due to turbulent vibrations, so this level of energy loss is much higher than that in laminar flow.

Pressure loss due to frictional resistance in a round duct is determined by

$$\Delta P = H = \lambda \frac{L}{D} P_v = 32{,}25 \cdot \alpha \cdot \frac{L}{D} \rho \cdot v^2$$

where

ΔP - Pressure loss (head loss) due to frictional resistance in duct L long, mm H_2O;

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P_v - Velocity pressure in duct, mm H_2O;

λ - Friction coefficient, dimensionless coefficient;

L - Distance between two cross sections of duct, m;

α - Friction factor for the duct, KgF,s^2/m^4;

D - Diameter of the duct, m;

ρ - Air density, kg/m^3;

V - Average velocity at the duct cross-section, m/s.

A relationship between pressure loss and friction factor in duct is given by

$$\frac{H}{L} - \frac{P1 - P2}{L} = 65{,}4 \cdot \frac{\alpha}{D} \cdot \frac{\rho}{2} v^2,$$

where

P_1 - Pressure of air at section 1;

P_2 - Pressure of air at section 2,

However, at present, there is not expression for calculating friction factor α. It has been determined experimentally,

3.2. Method of determination of duct resistance coefficient

One of the most basic ventilation equations describes a relationship between pressure loss and airflow volume in a duct is

$$H= \Delta P= R\cdot Q^2= R\cdot(v\cdot S)^2$$

Therefore, friction resistance in ducting system can be obtained by the following equation

$$R = \frac{H}{v^2 S^2},$$

where

R - Friction resistance, kμ;

S - Cross sections of duct, m^2,

From equation above, the specific resistance - r and friction factor of the duct can be found

$$r = R/L.$$

And friction factor α is determined by

$$\alpha = 0{,}25\cdot\frac{H\cdot D}{v^2\cdot L}$$

3.3. Experimental model for determination of duct resistance

Laboratory set-up: Experimental model for determination of duct resistance was set up at Institute of Mining Science and Technology - Vinacomin (IMSAT), Uong Bi, Quang Ninh.

Fig. 3.1. Experimental apparatus for determination of duct resistance

Fig. 3.2 shows the schematic diagram for determination of duct resistance.

Fabric duct was connected to the test setup. Fabric duct was connected directly to rigid steel ducting and carried as straight in the horizontal direction. The fan had the capability to blow the airflow into the duct.

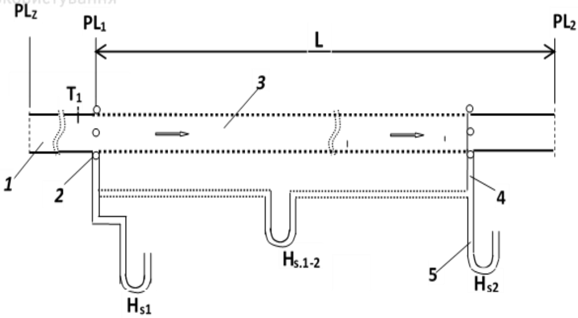

Fig. 3.2. Schematic diagram for determination of duct resistance: *1* - rigid steel ducting; *2* - holes for measurement; *3* - flexible fabric ducting; *4* - pitot-tube; *5*- U tube

According to the authours H.D. Goodfellow et al, the process of movement of the airflow in the duct is described by the conservation equation of energy and mass. For determination of duct resistance, assuming that:

- The air flow in the duct is turbulence flow;
- The density of the air is a constant.

Experimental model set up the conditions which must be satisfy the conditions as follows:

- The ducting system must be kept tight, straight during experimental procedures. Hence, the pressure loss on the ductwork was caused by frictional resistance, Since the duct from PL_1 to PL_2 has no joints, local resistance does not appear.
- The test duct length shall be required to arrive at a fully developed turbulent flow.

For the model to determine the resistance of the duct with diameter D=0,6 m and air flow Q=3,4 m^3/s, the velocity in the duct is as

$$v = 3{,}4 : \left[\pi * \left(\frac{D}{2} \right)^2 \right] = 12{,}02 \text{ m/s}$$

Reynolds number

$$R_e = \frac{v.D}{\nu} = \frac{12.02 * 0.6}{14.4 * 10^{-6}} = 500833$$

where ν is the viscosity coefficient of the air, ν=14,4×10^{-6}

Duct length between two cross sections of duct section must be satisfied

$$L = 0.639 * R_{в}^{0.25} * D = 10{,}2 \text{ (m)}$$

*Thus, for the duct with diameter D=*600 *mm, test duct length is set* 15 *m*.

For the duct of 0,7-1 m diameter, test duct length have calculated as the same above.

- The system had a fan to supply air flow. The variable speed control unit of the fan was used to obtain a fine adjustment of airflow under 12 m^3/s.

- Microclimatic conditions during experimental procedures was: temperature 26°C and humidity 62%.

The average velocities in the ducts were obtained using the following method:

Velocity v at the center of each section was measured by a pitot tube. The cross sectional area of the duct was equally divided into four areas, 16 points traverse as shown in Fig. 3.3.

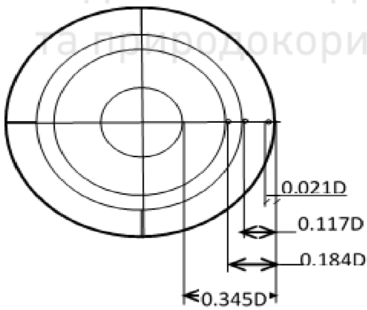

Fig. 3.3. Diagram position of traverse points in a circular measurement section for 4 - area, 16 point traverse

The average velocity *V* in the duct was calculated from the arithmetical mean value of *v*. From that the average velocities at the measuring of the pressure drops along the ducts can be estimated.

At the same time, the pressure difference between the pressure PL_1 and PL_2 was measured and related with the average velocity *V*.

Fig. 3.4. shows cross sectional area for the pressure measurement and pitots in practice

3.4 Results of determination of duct resistance

Experimental data for determining duct resistance *R*, specific resistance *r* and friction factors are shown in Table 3.1 by Phuong Thao Dang, Z. Malanchuk, et al.

Average values of the resistance *R*, specific resistance *r* and friction factors calculated for test ducting are as

$$\bar{R} = 0.4041\ \text{k}\mu;\ \bar{r} = 0.0269\ k\mu.m^{-1};$$

$$\bar{\alpha} = 0.00030\text{KgF}.s^2.m^{-4}$$

The values for the measured friction factor is small compare with published values calculated by others as shown in Table 1.1- Chapter 1.

The measured friction coefficient (0,0003 kgF·s^2/m^4) is much smaller with the value using the auxiliary ventilation design in Vietnam (0,00048 kg·F·s^2/m^4).

Table 3.1

Experimental data and results for determining duct resistance

Measurement	1	2	3	4	5
Airflow Q, m^3/s	7,33	7,42	7,42	7,42	7,43
Pressure at section PL_1, Pa	785	784	781	780	777
Pressure at section PL_2, Pa	558	569	553	564	555
Resistance R, kμ	0,4224	0,3902	0,4138	0,3921	0,40201
Specific resistance r, kμ/m	0,02816	0,02602	0,02759	0,02610	0,02680
Friction factor α KgF,s^2/m^4	0,00034	0,0031	0,00033	0,0003	0,00032

In Conclusion

- An experimental study was conducted to evaluate duct resistance. Experimental model set up the under controlled conditions in order to ensure reliability results.

- The measured friction coefficient (0,0003 kgF·s^2/m^4) is factor is small compare with the value using for designing the auxiliary ventilation in Vietnam (0,00048 kgF·s^2/m^4). Therefore, accurately estimating the friction coefficient is thus crucially important to design auxiliary ventilation in underground mine.

- The results of the duct resistance are to contribute to basis in the design and calculation auxiliary ventilation in Vietnam.

4. Determination of a relationship of duct leakage and parameters of ducts

4.1. Model for duct leakage

Study was conducted to investigate duct leakage along auxiliary ventilation ducting systems in Quang Ninh mine. Experimental data are made on 0,7 m, 0,8 and 1 m diameter ducts over sections of ducts installing towards the working face in Quang Ninh mine. Linear regression analysis fit these experimental data can derive the relationship between the air leakage coefficient, the quantity of the air in the ductwork and the ducting length.

It is shown how to derive the function indicating a relationship between leakage coefficient p and ducting length L(m), airflow in ducting system Q (m^3/s) supplied to the working face for different diameters of the duct by Phuong Thao Dang, Vu Chi Dang

$$p = f(L, Q) \tag{4.1}$$

Accordingly, assuming that air leakage coefficient in the duct-work can be described to be in the form of

$$p = 1 + c * L^a * Q^b \tag{4.2}$$

where p Leakage coefficient;

L - Duct length, m;

Q - Quantity of airflow in the ducting system, m^3/s;

a,b,c - constants,

The way to linear the equation (4.2) is to use the natural logarithm equation (4.2)

$$\ln(p-1) = lnc + alnL + blnQ \tag{4.3}$$

The experimental data are made on 0,7 m and 1 m diameter ducts over sections of ducts installing towards the working face in actual field conditions in Q_{uang} ninh coal mine.

Each set of data: $\ln(p_i)$, $\ln(L_i)$ and $\ln(Q_i)$ under given data – duct diameter, with i=1, 2…n.

With ducting length L_i, the quantity of airflow in the ducting system Q_i is measured; the air leakage coefficient p_i is calculated as $p_i = \dfrac{Q_0}{Q^i}$;

where Q_0 the quantity of airflow beyond the fan, m³/s;

Q_i the quantity of airflow reaching the end of the ducting length - L_i:

y_i, x_{i1}, x_{i2} and b_0 are denoted as: $\ln(p_i\text{-}1)$, $\ln L_i$, $\ln Q_i$ and $\ln C$ respectively.

Equation (4,3) can be rewritten

$$y_i = b_0 + b_1 x_{i1} + b_2 x_{i2}\,. \qquad (4.4)$$

Using linear regression analysis to fit these experimental data can derive the relationship between the air leakage coefficient, the quantity of the air in the ductwork and the ducting length, Least-squares regression is chosen coefficients b_0, b_1… and b_k such that the sum of squared residuals is minimum:

Multiple regression model with k independent variables

$$L = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 = \sum_{i=1}^{n} (y_i - b_0 - \sum_{j=1}^{k} b_j x_{ij})^2 \quad \to min \qquad (4.5)$$

i= 1,2,...n; j=1,2,...k

→ Least-squares must satisfy

$$\frac{\partial L}{\partial b_o} = -2[y_i - (b_0 + \sum_{j=1}^{k} b_j x_{ij})]^2 = 0 \qquad (4.6)$$

and

$$\frac{\partial L}{\partial b_j} = -2[y_i - (b_0 + \sum_{j=1}^{k} b_j x_{ij})]^2 x_{ij} = 0 \qquad (4.7)$$

The least squares normal Equations

$$\sum_{i=1}^{n} y_i = nb_0 + b_1\sum_{i=1}^{n} x_{i1} + b_2\sum_{i=1}^{n} x_{i2} + \cdots + b_k\sum_{i=1}^{n} x_{ik} \tag{4.8}$$

$$\sum_{i=1}^{n} x_{i1}y_i = b_0\sum_{i=1}^{n} x_{i1} + b_1\sum_{i=1}^{n} x_{i1}^2 + b_2\sum_{i=1}^{n} x_{i1}x_{i2} + \cdots + b_k\sum_{i=1}^{n} x_{i1}x_{ik} \tag{4.9}$$

…………………………………………………………………………………………

$$\sum_{i=1}^{n} x_{ik}y_i = b_0\sum_{i=1}^{n} x_{ik} + b_1\sum_{i=1}^{n} x_{ik}x_{i1} + b_2\sum_{i=1}^{n} x_{ik}x_{i2} + \cdots + b_k\sum_{i=1}^{n} x_{ik}^2 \tag{4.10}$$

The solution to the normal equations are the least squares estimators of the regression coefficients $b_o, b_1,\dots,b_k,$

Multiple regression model with two independent variables

Convert above system of linear equations to matrix form as:

$$\begin{vmatrix} \sum_{i=1}^{n} x_{i1}^2 & \sum_{i=1}^{n} x_{i1}x_{i2} \\ \sum_{i=1}^{n} x_{i1}x_{i2} & \sum_{i=1}^{n} x_{i2}^2 \end{vmatrix} \begin{vmatrix} b_1 \\ b_2 \end{vmatrix} = \begin{vmatrix} \sum_{i=1}^{n} x_{i1}y_i \\ \sum_{i=1}^{n} x_{i2}y_i \end{vmatrix} \tag{4.11}$$

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Use Cramer's Rule to find the values of b_1, b_2 and b_0,

4.2. Goodness of fit in linear regression

Total sum of squares - SS_{tot};

Residual sum of squares - SS_{reg};

Model sum of squares: SS_{model},

$$SS_{tot} = \sum_{i=1}^{n}(y_i - \bar{y})^2 ;\ SS_{model} = \sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2 ;\ SS_{reg} = \sum_{i=1}^{n} e_i^{\,2} = \sum_{i=1}^{n}(y_i - \hat{y}_i)^2$$

$$SS_{tot} = SS_{model} + SS_{reg}$$

➢ $$R^2 = \frac{SS_{model}}{SS_{tot}} = 1 - \frac{SS_{reg}}{SS_{tot}}$$

So R^2called "*coefficient of determination*" $0 \le R^2 \le 1$. If $SS_{reg} = SS_{tot}$= then $R^2=0$ and model is not useful. If $SS_{reg}=0$ then $R^2=1$ and model fits all points perfectly. Almost all models will be between these extremes.

Test of hypothesis on individual regression coefficients

Step 1: *Set up hypotheses:* (are all the coefficients really equal to zero?) H_0: $a=b=0$

H_1:H_0 is untrue $a \neq b \neq 0$

Step 2*:* Calculate test statistic F

$$F = \frac{R^2/k}{(1-R^2)/(n-k-1)}$$

Step 3: F_c (the critical F) can be found on the F-table with k df for the numerator and n-k-1 degrees of freedom for the denominator.

Step 4 Set decision rule: if $F \ge F_c$ then reject H_0.

4.3 Analyses data

Analyses data for the duct of 0,8m diameter measured at Ha Lam Coal mine Phuong Thao Dang, V.D. Bui.

Linear regression analysis to fit these experimental data can derive the relationship between the air leakage coefficient, the quantity of the air in the ductwork and the ducting length. Therefore, the air leakage coefficient for the ductwork of 0,8 m diameter can be estimated based on the experimental data at Ha Lam Coal mine by the regression method.

As a result obtained from Stata software, the air leakage coefficient for the duct of 0,8 m diameter can be found based on data at Ha Lam Coal mine

$$p = 1 + 1.3013 * 10^{-5} * L^{1.482658} * Q^{0.450381}.$$

Critical F was found on the F-table $F_{0,05}(2,19)=3,52$ with α=0,05, F calculate: $F(2, 19)=78,17$

L_{max}: Duct length total

So: $F > F_c$ 0,05 then reject H_0, This value would imply that the regression parameters are nonzero and the regression equation does have some validity in fitting the data.

For the duct of 0,6-1 *m diameter at Quang Ninh Coal mine have been analyzed as the same above.*

For duct of 0,6 m

$$p = 1 + 3.127.10^{-6} * L^{1.906} * Q^{0.5351}$$

For duct of 0,7 m

$$p = 1 + 2.0042048.10^{-4} * L^{1.051706} * Q^{0.677522}$$

For duct of 1,0 m

$$p = 1 + 2.554.10^{-5} * L^{1.164} * Q^{0.686}$$

Table 4.1

Experimental data for the duct of 0,8 m diameter measured at Ha Lam Coal mine

Face	S, m^2	Local fan	Q_o m^3/s	Q_{Face} m^3/s	Values of p_i correspond to ductwork length L_i (m) when extending driven roadways					
					L_{max} / p	L_1 / P_1	L_2 / P_2	L_3 / P_3	L_4 / $P4$	L_5 / P_5
Vent, Roadways of Longwall 1011-3-T-15 Area III, Seam 11	9,4	FBDN-6,0/2×22	6,8	5,4	380 / 1,259	60 / 101	120 / 1,015	240 / 1,079	380 / 1,2592	– / –
Vent, Haul Roadways level -270÷ -250 Area III-Seam 10	9,4	FBDN-6,0/2×22	6,8	5,2	482 / 1,316	100 / 1,03	180 / 1,0625	286 / 1,1333	360 / 1,214	452 / 1,308
Ven, Roadways level -50 Area VI- Seam 10	14,3	FBDN-6,7/ 2×30	8,6	6,6	590 / 1,303	140 / 1,062	220 / 1,117	320 / 1,1467	410 / 1,229	560 / 1,303
Ven, Crosscut level -70÷ -60 Area II- Seam 10	15,3	FBDN-6,7/2×30	8,6	7,0	452 / 1,223	100 / 1,062	180 / 1,103	240 / 1,117	340 / 1,147	410 / 1,212

In conclusion

- Factors such as duct size and diameter, aerodynamic parameters of duct influencing on duct air leakage have been examined.

The leakage coefficient of the ductwork can be determined based on the general evaluation of the influence of the factors, in which the duct length and diameter, airflow in the ductwork are very important.

A conceptual prediction model has been proposed based on the experimental data at Quang Ninh Coal mine. Using linear regression analysis to fit these experimental data can estimated the air leakage coefficient in the ducting systems in coal underground mines.

Also, the research result has been used to design mine auxiliary ventilation system, especially optimization of parameters of duct and fan in the auxiliary ventilation system.

The results of leakage coefficient contribute to data in the design and calculation of ventilation during the construction of the tunnel and underground works. Methodology in the thesis is the basis for finding multivariable functions in mine ventilation in particular and mine design in general.

Conclusion

In Quang Ninh, coal underground mines have high methane content and total length of new driven roadways is large for expanding mining areas and growing coal output. Ventilation is one of the most important considerations in coal underground mines.

In Viet Nam, in the past, due to flexible ducts were often imported from abroad, parameters of the duct as duct leakage, duct resistance were referenced from abroad handbook to design the auxiliary ventilation system.

However, currently, flexible ducts have often been produced domestically, investigation of air leakage and resistance of auxiliary ventilation ducting system in underground mine in Quang ninh has been undertaken.

Level of air leakage is mainly influenced by the following factors: total length, diameter of the ducting and airflow in the ducting system.

Deriving analytical expressions of a relationship between air leakage coefficient and duct parameters is done by semi-experimental methods.

Multivariable function: $p=f(L,Q,D)$ has been determined according to the linear regression method based on experimental data.

The measured friction coefficient (0,0003 $kgF \cdot s^2/m^4$) is much smaller with the value using the auxiliary ventilation design in Vietnam (0,00048 $kgF \cdot s^2/m^4$).

Accurately estimating the friction coefficient is thus crucially important to design auxiliary ventilation in underground mine.

Therefore, it is necessary to determine the resistance all types of the ducts being used in auxiliary ventilation when mining roadways driven in coal mines, specially, for a duct produced in Viet Nam.

Suggestions for further research

Based on the method applied in the thesis, it is recommended that institutes and manufactures carry on determination of the air leakage coefficient for all diameter of duct, as well as choose suitable materials to produce duct to avoid air leakage and resistance.

Suggesting Vietnam national coal - mineral industries holding corporation limited apply the research results on the resistance and air leakage coefficient to calculate the ventilation to ensure save cost and energy.

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INCREASING THE ENERGY-EFFICIENT EXTRACTION OF AMBER IN THE RIVNE-VOLYN REGION OF UKRAINE

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Abstract

The current state of development of the mining industry for the extraction of useful minerals in the Rivne-Volyn region is characterized by the presence of a significant number of industrially significant amber deposits, both being exploited and those that are not being developed due to the inability to extract them using traditional methods. The exploitation of such deposits is hindered by complex geological conditions, the significant distance from bodies of water, and the need to preserve the surface layer of soil, which requires additional reclamation work. The most promising way out of this situation is the introduction of the hydro-mechanical method of extracting minerals, which does not require reclamation work since the extraction of the useful mineral occurs without destroying the surface layer of soil by using hydraulic energy. However, the experience of using hydro-mechanical technologies for amber extraction from sand deposits indicates limiting factors - low productivity and highwater consumption. The latter factor is significant because water in regions where amber deposits are located is limited. The identified limiting factors for the hydro-mechanical extraction technology depend on the speed at which the useful mineral flows to the surface. If the extraction technology parameters can provide the maximum possible speed for the specific conditions of a deposit, this will allow overcoming existing limitations, reducing energy consumption and water usage, increasing productivity, and bringing new promising deposits into exploitation. Previous researchers have studied the process of amber flow during hydro-mechanical extraction from sand deposits exclusively experimentally. Therefore, there are no scientifically substantiated models that establish the relationship between the speed of particle flow and the physical and granulometric characteristics of the deposit, as well as the frequency of oscillations of the working element and

the air flow rate. This makes it impossible to determine rational flow rates for amber and air consumption that would ensure the best results for new deposits without conducting numerous experiments.

Introduction

Characteristics of amber and its deposits

Amber is found along the coasts of the Baltic Sea in the countries of the Baltic States, Poland, Germany, Denmark, Sweden, and Belarus. The largest deposit to date is the Primorskoye (Palmnikenskoye) deposit in the Kaliningrad region of Russia [1,2]. The main industrial value of amber comes from secondary coastal and marine deposits. Amber-succinite, fossilized resin from the pine tree Pinus succinifera, is found in several regions on the map of locations. In geological terms, Baltic amber is the most widespread. The same gemstone composition has been found in Ukraine (near Kiev, Kharkiv, and in Volyn). In Ukraine, the deposits of the Paleogene and Neogene include the Rivne (Sarnensky, Volodymyrets, and Dubrovytsia regions), Kyiv (Kyiv amber is the product of occasional washouts of fossilized resin, i.e., this source did not have a constant nature), Zhytomyr, Lviv, and Kharkiv regions [3,4]. The large Klesiv deposit (in Polissia) began to be developed relatively recently, as the succinite here is located quite deep underground.

Abroad, deposits are known in Primorye (Russia), Italy, Poland, Myanmar, Canada, the United States, the Dominican Republic, and Mexico, but 90% of the world's amber reserves are mined in the Kaliningrad region (Russia). The Baltic deposit belonged to Germany for a long time, but after 1945, it was ceded to the Soviet Union [5].

Amber-containing deposits are found at varying depths, with greater depths found further from the Baltic Sea. Therefore, amber has long been extracted from the Baltic Sea coast, from the island of Rügen to the Western Dvina. This stone is found in the sands of the Baltic Sea. Amber-containing strata are located below the level of the Baltic Sea, and the surf often washes small pieces of amber from them, throwing them onto the shore. It is especially common near Kaliningrad. In the settlement of Yantarny, a large plant has been operating since 1965. Yantarny is home to one of the largest industrial deposits in the world. Amber products extracted from the Baltic Sea coast have been present in Europe for a very long time - there are preserved pendants, rings, animal and human figurines, small amulets, whose age is several millennia.

Erosions and landslides, as well as subsequent glaciers, have spread amber over long distances. Secondary amber deposits have been found in Poland, Germany, Denmark, Belarus, and Ukraine [6,7].

The Klesiv amber deposit is the only one in Ukraine associated with Paleogene deposits. According to the Ukrainian geologist V.I. Panchenko, it is located in the zone of framing of Proterozoic crystalline rocks of the northwestern part of the Ukrainian Shield by Paleogene sedimentary formations. The scatter consists of several areas, two of which are open pit mines 472 and 43 (Velyky Puhach). This area is located 1-4 km northwest of the Klesiv station. The productive horizon of the deposit consists of three sandy layers composed of different-sized quartz sands, which are unevenly enriched with clayey material, organic matter, and amber. The lower layer is sporadically enriched with glauconite, which gives the amber-bearing rock a blue tint. Amber pieces can reach a size of 10 cm. According to V.I. Panchenko and O.S. Tkachuk [8], the amber content in the deposit ranges from 15 to 310 and even 1000 g/m^3, with an average of 50 g/m^3. The rock mass of the Klesiv deposit is a valuable material for the production of amber products.

The distribution of amber is uneven, with the maximum concentration at the base of the deposit. The age of the deposits has been determined through spore-pollen analysis and is classified as early to middle Oligocene and late Oligocene. The annual production of amber at the Klesiv deposit does not exceed 140 kg. Klesiv amber has gained recognition on both domestic and foreign markets in a short time.

Significant deposits of valuable amber have been explored in Ukraine. Nearly six percent of the world's amber reserves are found in the Rivne region. Extraction work is currently being carried out at the Klesiv deposit (Sarny district) and in the Volodymyrets (village of Berezhnytsia) and Dubrovytsia (village of Vilne) districts. The total reserves are estimated at 100,000 tons, mostly located in sandy and sandy-clay soils at depths of up to 15 meters, and are sufficient for further exploration and the implementation of new technologies.

Physical-mechanical and chemical properties of amber

Amber is a high-molecular organic acid compound that contains on average 79% carbon, 10,5% hydrogen, and 10,5% oxygen. Its formula is $C_{10}H_{16}O$. In 100 g of amber, there are 81 g of carbon, 7,3 g of hydrogen, and 6,34 g of oxygen, as well as small amounts of sulfur, nitrogen, and minerals. During the process of oxidation (weathering), the oxygen content of amber increases, while the content of other components decreases. Amber contains 24 chemical elements as impurities (from traces up to 3%), including Y, V, Mn, Cu, Ti, Zr, Al, Si, Mg, Ca, Fe, Nb, P, Pb, Zn, Cr, Ba, Co, Na, Sr, Sn, Mo, and Yb. 17 of these elements were found in the lowland amber of the Klesivske deposit, 12 in the amber of the Beach area of the Prymorske deposit, and 11 and 13, respectively, in the amber of the Kurshska Kosa and the Carpathians. The transparent variety of amber has the lowest number of chemical elements. This mineral can have white, yellow, greenish, blue, red colors, but the typical colors are orange and golden-yellow varieties. Amber is amorphous, soft (hardness of 2,2-2,5 on the Mohs scale), viscous, easy to grind and polish. Its density ranges from 1,05 to 1,096 g/cm^3. In the classification sense, this mineral is a representative of the group of combustible minerals - humic coal of the "leptobiolith" rank. In chemical terms, it is a high-molecular organic acid compound with an approximate formula of $C_{10}H_{16}O$, usually with sulfur impurities. At a temperature of 150°C, amber softens, and at 300°C, it melts. It burns easily, emitting a resinous smell. The mineral has dielectric and heat-resistant properties and is found in nature as grains and pieces ranging in size from 1 to 10-20 cm or more in diameter, including very large pieces up to 10 kg in weight. The shape of the pieces can be any: drops, droplets, various irregular shapes, and porous plates.

In scientific literature, the term "Baltic amber" or "succinite" typically refers to resins containing succinic acid. The content of succinic acid in Baltic amber (succinite) ranges from 3 to 8%. Depending on the type of amber, it is distributed differently. Transparent amber contains 3,2 to 4,5% succinic acid, Bastardo amber contains 4,0 to 6,2%, bone amber contains 5,5 to 7,8%, and oxidized bark contains 8,2%. The composition and structure of amber continue to be studied. Its light fraction (about 10% of the mass) has long been known. These are aromatic compounds - terpenes with 10 carbon atoms and sesquiterpenes with 15 carbon atoms in the molecule. Mass spectrometry studies have shown that more than 40 compounds are included in amber. Many of them are still unknown. Abietic acid and its isomers have been isolated from amber in a pure form. They make up a soluble part (20-25%) of Baltic amber in organic solvents. Mineral inclusions in amber are represented by iron sulfide - pyrite and bituminous substances. Among the gas inclusions in amber, CO_2,O_2,H_2,Ar,Kr,Xe, and Ne have been detected, among which nitrogen predominates. The residue of amber is insoluble in any known solvents. IR spectroscopy data showed that "succinite" contains lactone (complex ether) groups, meaning it is a complex ether. In addition, amber constantly contains succinic acid (about 4%) and impurities of salts (mostly succinic acid salts) of potassium, calcium, sodium, and iron (up to 1%). Thus, amber consists of three groups of compounds: volatile terpenes and sesquiterpenes; soluble organic acids; and insoluble polyethers of these acids with alcohols that are formed from the same acids [11-16].

Rivne amber differs in its chemical composition. It is the most saturated with impurities and contains 18 chemical elements. In addition to silicon, magnesium, iron, and calcium, which are present in almost all deposits, there are also additives such as lead, zirconium, and up to 3,19% sulfur. The solubility of Ukrainian amber is 8,7%. This affects the quality and color of the solidified resin. Amber is a mineral of the organic compound class, resin of coniferous trees mainly of the Paleogene period. The composition of amber includes volatile aromatic oil, two soluble fractions of resin, amber acid, and 90% insoluble fractions. Amber is an amorphous polymer, has a multitude of colors, and gives a specific IR spectrum (700-1900 cm^{-1}), which distinguishes amber from other similar resins. The melting temperature is t=365-390°C. Specific gravity is 1000-1100 kg/m^3 (in the Baltic, it is also 970 kg/m^3, and in the Carpathians - 1220 kg/m^3). It is easily mechanically processed. It is not soluble in water (partially soluble in alcohol - 20-25%, ether - 18-23%, chloroform - up to 20%), but can swell and increase in volume up to 8% when left in it for a long time. It completely decomposes in hot concentrated nitric acid and can soften at t=100 °C.

The cost of amber depends on the uniqueness of the samples and is established collegially by experts. A methodology has been developed to determine the value, which includes the classification of pieces of amber by shape, size, and color. The cost varies from \$3000 per 1 kg of amber of *A* form, size 1, and color 1 to \$5 for amber of *C* or *D* form, size 5, and color 1-4. For finished products of standards *A*,*B*,*C*,*D*, and E, the cost varies from 0,4-0,5 to 1 $/g.

Review and Analysis of Existing Methods and Technologies for Amber Extraction

Through analysis of literature sources, it has been established that currently, amber extraction from sand deposits is primarily carried out using two methods: mechanical and hydraulic. Researchers such as M.G. Lustyuk, V.Ya. Kornienko, Ye.A. Kononenko, Yu.M. Mishin, and others have studied the problems of amber extraction [17-21].

The mechanical method involves mechanical excavation of the soil mass in an open pit or underground. This method is used at the Klesivskyi deposit and involves the following steps: opening up the productive soil layer, excavation work, transporting the rock from the excavation site to the screening plant, where the amber is separated from the rock through washing, and land reclamation [22]. The disadvantages of this method are high operational and economic costs, removal of rock to the surface, and negative environmental impact. Moreover, this method is outdated, utilizes less productive equipment, and leads to significant losses of the valuable mineral.

The hydraulic method involves washing the productive soil layer with high-pressure streams and extracting amber from the deposit using hydraulic flow [23,24]. According to the research of M.G. Lustyuk [22], the method of hydraulic well mining of minerals includes opening up the productive horizon with wells around the mining chamber, casing them, installing hydraulic mining equipment with an ejector, connecting wells, cutting the productive horizon, filling the cut slot with water, destroying the rock of the productive horizon in the cut slot, hydro-erosion of rock in the flooded workings, and lifting the pulp to the surface by self-pouring along the well due to the constant influx of fluid in the working area in the center of the mining chamber [10-13].

In private mines, amber is mined exclusively by the hydraulic method with a low level of mechanization and large losses of amber due to the imperfection of the mineral extraction technology from sand deposits. Other methods of well extraction of minerals are also known, for example, using mixtures of different viscosities.

Thus, a viscous, non-freezing liquid is fed into the prepared well, which forms pulp with the soil mass, and due to the difference in density, heavier fractions sink down the well, and lighter fractions are carried along with the soil mass by pumps that pump out the pulp to the surface of the deposit. This method is used for extracting materials from frozen soils, as well as for sorting minerals of different densities.er, all of them are accompanied by the removal of mineral soil to the surface of the deposit, do not ensure the complete extraction of amb

However from the deposit, are energy-intensive, lead to a change in the soil structure, the formation of voids and, accordingly, have a significant negative technogenic and ecological impact on the environment.

At the Klesivskoye deposit in the Rivne region, amber is mined using an open pit method. Amber lies in sandy soil. The depth of occurrence is up to 15 m. There is a granite quarry with a significant water supply near the deposit. The deposit is located close to roads and the power grid.

In the Baltic region and the Kaliningrad region of the Russian Federation, amber is mined using the quarry method, with the development of deposits by dredgers and the use of hydromonitors. Today, a hydraulic method is also known, which is accompanied by the injection of liquid into the amber massif followed by the pumping of the soil pulp to the surface of the deposit.

The methods of destruction of rock, which contains a useful component, mainly depend on its strength. Separation of particles of loose and weakly cemented rocks is carried out by creating a filtration flow with the required amount of hydraulic gradient in the formation. Intensification of the rock destruction process is possible under the influence of vibration, explosion, chemical or microbiological decay of the cementing substance. Ruined rock is fed to the suction nozzle of the outstanding device either by gravity flows (with a sufficient slope of the bottom of the chamber) or pressure flows of water. The rise of the hydraulic mixture to the surface is carried out using an airlift, a hydraulic elevator, a submerged dredger, or by creating a back pressure of water or air injected into the deposit.

Management of the mining process is carried out from the surface by changing the flow and pressure of water, as well as places of influence of the working agent and places of selection of the useful component [8].

Melnikov N.V., Arens V.Zh, Chernei E.I., Malanchuk Z.R. [9-12] believe that the basis for using hydrotechnology is the results of field exploration. In such studies, the developers do not take personal participation. The task is reduced only to the clarification of individual mining and geological indicators on the basis of laboratory studies of the physical and mechanical properties of the mineral and overlying rocks.

A significant contribution to the solution of the problem of the interaction of the stream and the mountain massif was made by the works of M.A. Lavrentiev, B.V. Voitsechovskyi, Y.A. Kuzmich, R.A. Atanov, B.A. Teodorovych, A.M. Zhuravskyi, R.N. Nikonov, V.S. Muchnyk, N.F. Tsyapko, V.N. Poturaev, A.F. Bulat, V.P. Natutyy, B.O. Blyuss, V.F. Khnykin, E.I. Chernei, Z.R. Malanchuk, N.R. Malukhin, N.I. Babichev, O.M. Prokopyuk, V.Ya. Kornienko. According to the data presented in the studies [8-13], it was established that researchers do not have a single opinion regarding the theory of hydraulic fracturing and there are many hypotheses united by a group of factors that influence the fracturing process, the values of which and their specific weight are basically not learned At this stage, the management of the hydraulic extraction process and the documentation of extraction chambers are insufficiently considered.

The main characteristics of the deposit when choosing development parameters are the physico-mechanical properties of the ore and host rocks, the dip angle and thickness of the ore seam, the thickness of the overlying rocks, and hydrogeological conditions .

The physical and mechanical properties of the rock determine the most important parameters of hydraulic extraction process: specific flow rate and required pressure of water for destruction and washing, parameters of hydrotransport of rocks, dimensions of the washout map. These same properties largely determine the choice of the main equipment (pumps, hydraulic monitor, dispensing mechanism). The physical and mechanical properties of the ore depend on losses and desalting during mining, crushing during hydraulic transportation, flocculation and water yield during storage.

The shape and elements of the occurrence of ore bodies have a great impact on the effective use of hydraulic mining. The contact conditions of the containing rocks of the roof and sole determine the loss of ore and methods of delivery (washing) in the chamber. The capacity of the ore layer largely determines the volume of production from one chamber and thereby the economic efficiency of the method. However, the value of the mineral plays a big role here. It may be that the high value of the ore allows efficient development of low-grade ore deposits. According to the conditions of clean extraction, it is advisable to divide ore bodies into thin (up to 0,8 m), low-power (0,8-2 m), powerful (2-15 m) and very powerful (more than 15 m). According to the dip angle, the layers are horizontal (0-5°), flat (5-15°), inclined (15-45°) and steep (greater than 45°). The angle of fall of the formation determines the method of delivery of destroyed ore to the suction of the delivery mechanism, the greater the angle of fall of the formation, the better the delivery conditions in the chamber.

Generalized technological scheme of hydraulic erosion and lifting of mineral according to V.Zh. Arens is shown in Fig. 1.

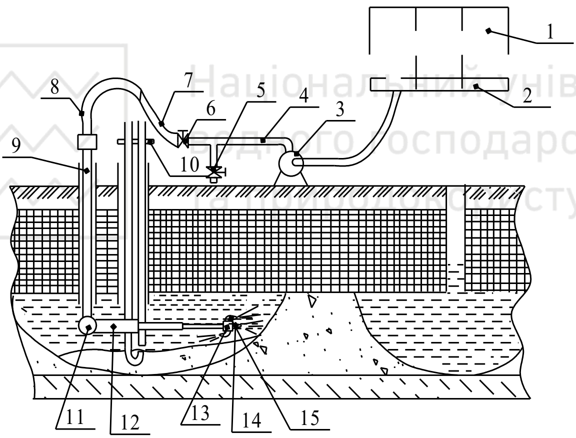

Fig. 1. Generalized technological scheme of hydraulic erosion and lifting of mineral: *1* - map of alluvium; *2* - sump; *3* - centrifugal pump; *4* - water pipe; *5* - reset latch; *6* - latch; *7* - flexible hose; *8* - upper swivel knee; *9* - vertical status of the hydromonitor; *10* - hydraulic elevator; *11* - lower swivel knee; *12* - telescopic barrel; *13* - head; *14* - central nozzle; *15* - side nozzles

One of the main technological processes in hydraulic mining is the destruction of rock and the transfer of minerals into a mobile state. Physical-geological, hydraulic and technological factors affect the intensity of the process of hydraulic destruction of rocks during hydraulic mining. Physical and geological factors include strength, hardness, composition, structure, texture, porosity and cracking, wettability, water permeability, viscosity. In general, they characterize erosion of the rock [42]. The hydraulic factors include pressure and flow rate, that is, the characteristics of the jet of the hydromonitor. Among the technological factors are the conditions of the impact of the jet on the hole (speed of movement of the jet relative to the hole, the angle of meeting the jet with the hole, the order of extraction - all this characterizes the working conditions).

The application of geotechnological methods of mineral extraction determined the choice of the working agent - water, which ensures: fluidity and low operational efficiency of processes, remoteness of extraction with high mechanization and automation, wide use of low-labor-intensive and low-energy gravity hydraulic transport, intensification of processes, combination in favorable conditions of the phases of the working agent to increase intensity and efficiency of systems. Elements of the systems directly related to clean extraction, in order to achieve optimal operating modes of hydraulic mining equipment, must necessarily be balanced according to the consumption of the working agent [9].

In addition to the working agent, the main elements of the testing and development systems include the erosion of the main and underlying rocks and the hydrotransportation of mineral raw materials. Erosion is a process that involves the rock being dislodged by a jet stream from a hydromonitor and directed towards an automated well hydromonitor or discharge production. The efficiency of erosion is determined by the productivity of the hydromonitor and the specific water consumption. Analysis of studies on rock destruction has shown that there are various hypotheses about the mechanism of the process, but a general theory of destruction under the influence of a hydromonitor jet stream is currently insufficiently developed [20-23].

Hydrogeological conditions affect the choice of mining equipment and the scheme for working the ore deposit. If the water inflow is small, the water can be pumped directly from the chamber and the extraction can be carried out in an unwatered excavation. With a large water inflow, the extraction can be carried out in a flooded excavation. However, in this case, the processes of destruction and delivery of useful minerals in a flooded excavation are significantly complicated [14].

It is known that the parameters of hydraulic mining are related to the characteristics of the surrounding environment [15], so all easily dispersible, porous, loose, and weakly connected deposits of minerals are promising for hydraulic mining. These include deposits of peat, sapropels, building materials; placer deposits of gold, lead, amber, diamonds, titanium, zirconium; sedimentary deposits of rare and radioactive ores; iron ores, oxidized and mixed manganese ores, non-metallic minerals; phosphates, clay bauxites, zeolites, coal, metal-bearing shales, bitumens.

However, despite the significant positive experience in implementing the hydraulic mining technology in production and positive economic results, there are a number of problems that prevent widespread adoption of hydraulic mining technologies for industrial mining of minerals.

The swampiness or complexity of the relief above the ore body affects the design and type of equipment used for mechanizing mining operations, drilling rigs, pipe layers, and transportation.

The main equipment required for the geotechnological mining method can be divided by purpose and placement in the technological scheme into three groups [19]. The main methods of rock destruction during hydraulic mining include hydrodynamic (hydromonitoring, hydro-impact, depression), mechanical, and combined. The hydro-monitoring method of rock destruction involves the use of high-pressure liquid streams from various types of hydro-monitors on the productive formation.

The hydro-impact method of rock destruction is carried out by the action of hydraulic shock waves (water hammers) of a non-jet nature in the inflow zone of the well.

The depression method is implemented by reducing the hydrostatic pressure in the well on the productive formation, which disrupts the equilibrium of forces that determine the stressed state of the rocks. In this case, the mountain pressure of the overlying layer or the reservoir pressure of the productive horizon exceeds the hydrostatic pressure, which is accompanied by collapse or crumbling of the rocks, or the flow of a water-saturated mass of unconsolidated particles.

The mechanical method of rock destruction is carried out using special side and percussion rock-breaking tools that are part of wellbore shells. In addition, mechanical destruction can be carried out by the action of abrasive particles that move with the flow of liquid on the rock.

Currently, according to M.I. Babichev [8], the most widespread method of rock destruction during hydraulic mining is using high-pressure hydro-monitoring streams. The use of water streams for rock and ore destruction is becoming increasingly diverse and wide-spread in mining and other industrial fields. There is now extensive experience in using hydro-monitoring streams for hydraulic mining of rock mass during open-pit and underground mining, as well as for extraction and processing of building stone. M.I. Babichev [8] provides general information on the experience of using hydro-monitoring streams in mining. His work includes information on the experience of using hydro-monitoring streams for hydraulic mining, as well as the operating parameters and capabilities of different types of hydro-monitoring streams.

Analytical methods based on stream theory, such as the so-called free turbulence, are also known, but they have a significant disadvantage because they do not take into account the influence of initial and boundary conditions of the stream's geometric and hydrodynamic parameters during its discharge from the nozzle. Many studies have an applied character and solve partial problems, which can be successfully used for calculating stream parameters for specific conditions [1].

Based on a series of studies of the erosion process followed by sand hydro-transport, S.M. Shorokhov [2] proposed a method for calculating the optimal erosion parameters under constant erosion radius conditions.

The choice of optimal elements and system parameters for testing and development is related to mining and geological conditions and the characteristics of standard equipment, and under conditions of unmanned excavation, the optimality indicator affects the quality of mining and the completeness of excavation [3].

The quality of individual components (nozzles, diffusers, suction devices, etc.) and equipment in hydraulic mining systems is of particular importance because water is the working agent, and poor equipment manufacture not only worsens technical and economic indicators but also makes it impossible to carry out the process as a whole [4].

An analysis of the current state of stream impact on rock surfaces shows that the current theoretical and experimental methods have a limited range of applications, and further research is needed to improve the efficiency of the process.

Analysis of the peculiarities of amber hydro mining

The current state of mining development in the field of extraction of ore and non-ore minerals in the Rivne-Volyn region is characterized by the presence of a significant number of industrially significant deposits that are not being developed due to the inability to exploit them by traditional methods, as they are located in complex hydrogeological conditions with high groundwater levels and bogging. Exploitation of such deposits by traditional underground methods is ineffective and costly.

Hydro mining of minerals, which is carried out using hydraulic energy to break down rocks, transport the broken rock to the sluicing field or well, and lift it to the surface, allows for effective development of such deposits. Hydro mining is one of the geotechnological methods of mineral extraction. The essence of hydro mining is to bring minerals in the place of occurrence into a movable state by hydro-mechanical influence, and to extract them in the form of a hydro-mixture on the sluicing field or at the surface of the well [5].

The complexity and large number of possible technological processes for extraction, as well as the specific operating conditions of deposits, indicate that in order to study and develop geotechnological methods, they need to be systematized. According to Z.R. Malanchuk [5] and E.I. Cherney [6], it is appropriate to systematize them based on the essence of the process underlying the extraction technology. Methods based on chemical processes, methods based on physical processes, and combined methods are distinguished based on this characteristic [7].

The choice of development method is determined by the geotechnological properties of the minerals (the ability of the minerals to move under the influence of working agents) and the physical-geological environment, which together with the geological and hydrogeological conditions reflects the characteristics of the properties of rocks and their fluids (porosity, permeability, fissuring, content of useful components, mineralization of water).

The main condition for the application of geotechnological methods is the real possibility and economic feasibility of converting the mineral into a movable state under the influence of working agents. In addition, it is necessary to provide the ability to supply working agents to the surface of the interaction and to remove the mineral through wells to the surface.

It is considered that ideal testing and development systems for the proposed methods should be those that, through a combination of qualitative and quantitative, technical, and technological parameters, allow the concentrate to be obtained in place of the deposit, leaving enclosing rocks in the subsurface.

With the development and implementation of geotechnological methods for extracting minerals, there is a need to determine new and refine a number of constant concepts in mining science related to the subject of research. The establishment and implementation of well hydraulic testing as a geotechnological method for exploration and trial exploitation of deposits was first made by Professor E.I. Cherney [8].

One should not limit oneself to the hydro-mechanical influence, as the purpose of geotechnology and its components, including hydraulic mining, is to influence the valuable mineral by working agents in the extraction process to put it into a mobile state. There are systems in which the borehole(s), as an element of the system, are absent. For example, removable chambers that are reconnaissance workings in the systems of mechanical-hydraulic testing (MHT) and mechanical-hydraulic mining (MHM) [9, 10].

Many researchers, including N.N. Maslov, have studied the liquefaction of sandy soils experimentally. Theoretical and experimental studies have also been conducted by O.E. Vlasov, H.M. Lyakhov, N.M. Dmitriev, V.I. Bilokopytov, A.M. Aronov, and others [11-16].

The influence of vibration technology on the soil environment was studied by A.F. Bulat, V.N. Poturaev, V.P. Franchuk, V.P. Nadutyy, Ye.S. Lapshin, K.K. Sofiysky, A.M. Zorin, L.M. Vasilyev, V.A. Lenda, A.D. Uchitel, L.A. Vaysberg, I.I. Blekhman, L.B. Levenson, I.F. Honcharevych, P.I. Pylov, E.A. Nepomnyashchy, E.I. Nazimko, A.O. Bondarenko, and several others [11-14].

At the National University of Water and Environmental Engineering (NUWEE), a hydro-mechanical method for lifting amber to the surface of a sandy deposit has been developed [15-18].

The essence of the proposed method is that the massif is saturated with water and activated by mechanical excitation to form a solid suspension layer of such density that an expulsion force arises, which lifts the amber to the surface of the deposit. By mechanical action, in the presence of water in the massif, the massif is brought to the complete loss of connections between the particles, the release of amber, and the achievement of a suspension state with a density that is greater than the specific gravity of the amber, allowing it to float to the surface of the deposit by the Archimedes force.

To implement the method, it is necessary to immerse rods in the form of pipes into the amber-bearing massif, from which water and air are supplied, and on which mechanical exciters are attached to excite the massif.

The process of soil liquefaction occurs as follows. Rods with biconic vibration emitters are immersed in the amber-bearing massif using the vibration method, while water and air are simultaneously fed through them into the soil massif. The array of vibration emitters is driven into oscillating motion, while a zone of solid boiling of the soil is formed. Amber is separated from the massif and floats to the surface under the action of the pushing force. The suspension medium allows the vibrating device to move freely in the longitudinal direction.

The use of a vibrating machine for the extraction of amber from deposits allows you to achieve extraction of amber from the deposit, increase labor productivity, reduce energy consumption and negative technogenic and ecological impact on the environment.

In order to increase production volumes while reducing cost, the industry needs the introduction of modern technologies in amber mining. In the absence of funding, there are no state investments in this industry. The extraction of amber in the old way requires a lot of money and time to extract and process large volumes of soil to obtain amber.

Thus, today, amber mining requires new technologies and the development of means to intensify the extraction process, which achieves high productivity and efficiency, as well as reduces the negative environmental impact on the environment.

Analysis of technical and technological features of amber extraction

Mechanical method of extraction of amber

Due to the fact that amber is found in sand in the Rivne-Volyn region, its extraction from sand deposits is mainly carried out by two methods: mechanical and hydraulic [18].

The mechanical method includes the mechanical development of the soil massif in an open pit (Fig. 2). Extraction of amber in this way includes: opening of the productive layer of the soil, excavation work, transportation of the rock from the place of development to the screening, where amber is separated from the rock by washing, land reclamation.

Mechanical extraction of amber is carried out as follows. After opening the productive layer of soil, the excavator places the mined rock in the dump cone on the upper platform. The rock cone is eroded by a hydraulic monitor, and the formed pulp enters the earth suction unit. Large pieces of amber are extracted in the quarry by catching them by hand. Next, the dredger pumps the pulp from the pit to the beneficiation unit. Pulp pumping is not only a transport, but also an important technological operation. More than 90% of the pulp is removed from the process and disposed of in tailings. Next, the material enters drum separators for enrichment and is sorted on sieves.

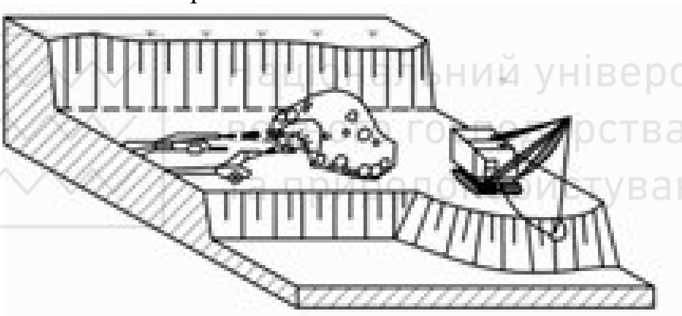

Fig. 2. Mechanical method of amber extraction

The disadvantages of this method are high operating and economic costs, removal of rock to the surface and negative ecological impact on the environment, and significant losses of fine-grained amber.

Hydraulic method of amber extraction

The hydraulic method is carried out by washing the productive layer of soil with high-pressure streams and carrying the amber to the surface of the deposit with hydraulic flows. This method is used in areas where mechanical methods are not possible, such as areas with high groundwater levels, protected areas, deep amber deposits, or its localization in certain places.

The method of hydraulic well mining of minerals (Fig. 3) is implemented as follows. Peripheral wells are drilled deeper than the level of the productive horizon along the contour of the mining chamber, with a diameter sufficient to accommodate hydraulic mining equipment. In the center of the mining chamber, an additional output well is drilled with a diameter that would provide free passage for amber of maximum diameter. Wells are lined with casing pipes up to the boundary of the productive horizon. Then hydraulic mining equipment, including a hydro-monitor and an output device, is placed in the peripheral wells.

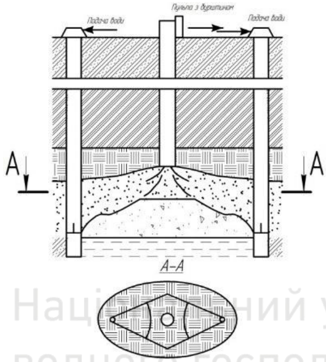

Fig. 3. Erosion of the next layered productive horizon

The hydromonitor is brought to the level of the boundary of the underlying rocks, which are eroded, forming a horizontal undercutting gap at the boundary with the productive horizon. By rotating the hydromonitor in the horizontal plane, a sector of erosion is formed within the extraction chamber. To reduce the time of formation of the undercut gap, erosion is carried out in a drained pothole. When extracting the pulp to the surface, a dispensing device is used.

After the formation of an undercutting gap, the hydromonitor is brought to the level of the first undercutting layer of the productive horizon. Hydromonitors form an undercut slot with a direct slope towards the additional discharge well, and the lower end of the casing pipes is raised to the top point of the roof of the first undercut layer. In the process of forming an inclined undercut, the horizon is filled with water up to the level of the dispensing device. As the inclined undercut crevice deepens, the layer of the productive horizon collapses into the created space of the undercut crevice. After connecting the undercut slot with the upper end of the casing pipes, the rise of the pulp is stopped and erosion in the face of the collapsed layer begins. At the same time, disintegration of rock particles is ensured and amber is freed from connections with the soil massif. The clay fraction turns into pulp, the density of which reaches 1,2 g/cm^3. Sand precipitates as a heavier fraction. Since the specific gravity of amber is 1,00-1,11 g/cm^3, it rises to the lower end of the casing pipes due to the pushing force and force of the pulp flow. After the erosion of the first collapsed layer of the productive horizon, the hydromonitor is brought to the level of the second layer, and the casing pipes are raised to the upper point of the roof of the second undercut layer, an undercut gap is formed and the second productive horizon is eroded. Operations are repeated until the entire productive horizon is fully developed.

There are other well-known methods of amber mining, for example, using mixtures of different viscosities. Thus, a viscous non-freezing liquid 5 is fed into the prepared well 1, which forms pulp 3 with the soil mass 2, and due to the difference in density, the heavier fractions fall down the well 4, and the lighter fractions are carried out together with the soil mass by pumps 7, which pump out pulp 6, to the surface of the deposit (Fig. 4). This method is used for extracting materials from frozen soils, as well as for sorting minerals of different densities [19].

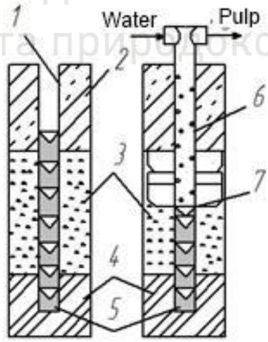

Fig. 4. The method of extraction of amber through wells

The considered methods have a significant drawback, since all of them are accompanied by the removal of mineral soil to the surface of the deposit, do not ensure the complete extraction of amber from the deposit, are energy-intensive, lead to a change in the soil structure, the formation of voids and, accordingly, have a significant negative technogenic-ecological impact on the environment.

Hydromechanical method of amber extraction

A hydromechanical method of raising amber to the surface of a sand deposit was developed at the National University of Water Management and Nature Management [20].

The essence of this method is that the massif, saturated with water, is activated by mechanical excitation (vibration excitation) until the formation of a solid suspension layer of such a density that a repulsive force arises, which raises the amber to the surface of the deposit.

That is, by mechanical action in the presence of water in the massif, we bring it to the complete loss of connections between particles, the release of amber and the achievement of a suspension state by the medium with a density greater than the specific gravity of amber, which allows the latter to float to the surface of the deposit due to the Archimedean force.

The method is implemented as follows: rods in the form of pipes, from which water is supplied and on which vibration exciters are fixed, are immersed in the amber massif using the vibration method.

At the same time, the array is saturated with water and vibration exciters are brought into oscillating motion.

Amber is freed from its bonds with the environment and floats to the surface.

The implementation of the method during the complete extraction of amber from the deposit allows to exclude the release of mineral rock to the surface of the deposit, and thus to reduce the negative man-made impact on the environment, to increase labor productivity with a decrease in general economic costs.

Today, the means of vibration impact on the soil environment are widely used when piling piles, pipes, casings, and piles are buried in the soil; during development (Fig. 5) and processing of soils, drilling of wells, compaction of particularly loose and water-saturated sandy soils.

Such means, as a rule, include vibration generators (vibrators), vibration weapons with vibration emitters; equipment for measurement, control and management of vibration; devices for preventing, extinguishing, isolating the harmful spread of vibration.

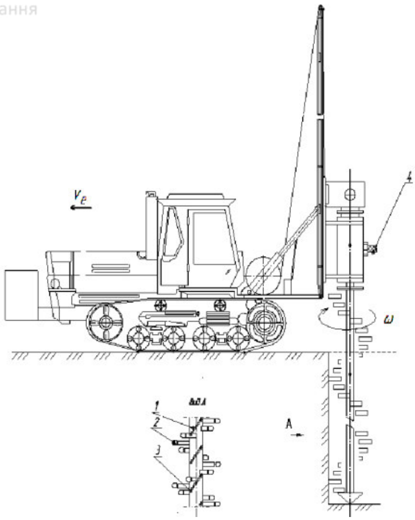

Fig. 5. The working body of the earthmoving machine for the extraction of minerals: *1* - hollow shaft; *2* - incisors; *3* - holes spaced in height; *4* - water supply hose

Powerful vibrating equipment is installed on a special base or suspended from crane installations (Fig. 6).

The deep vibration compactor consists of a mechanical vibrator 1 located on a platform 2, which transmits vibrations to a rod 4 with biconical vibration emitters 3 (Fig. 7).

Projectiles with biconical vibration emitters are the most effective in terms of volume transfer of vibration forces.

Therefore, they are the basis for the creation of vibro-hydraulic intensifiers for the extraction of amber from sand deposits.

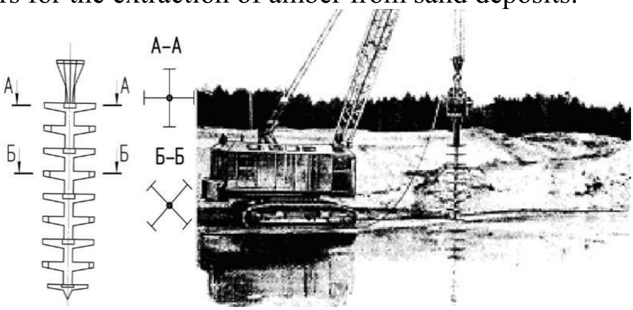

Fig. 6. Installation of VUUP-6

The existing vibrators are designed to achieve maximum soil compaction. Among them, vibration guns with screw (Fig. 7) and biconical vibration emitters (Fig. 8) should be singled out.

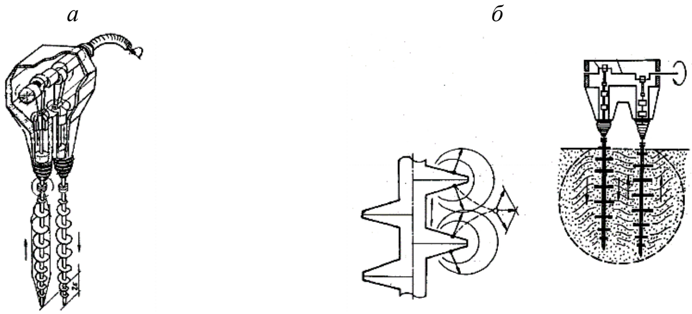

Fig. 7. Deep vibration compactor with screw vibration emitters

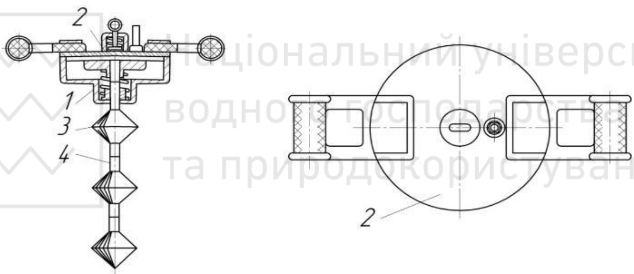

Fig. 8. Deep vibratory compactor with biconical vibratory emitters

The vibro-hydraulic intensifier for the extraction of amber from sand deposits (Fig. 9) [21] includes a vibration exciter 3 and biconical vibration emitters 5 spaced on vertical rods 4 (which are made of hollow bodies). Cone tips 6 are installed at the ends of the rods 4. The vibro-hydraulic intensifier is fixed on the attached equipment 2, which is attached to the running equipment of the tractor 1.

The process of soil liquefaction occurs as follows. Rods 4 with biconical vibration emitters 5 are immersed in the amber-bearing array by the vibration method, while simultaneously feeding through them and conical tips 6 into the water array. The array of vibrating emitters 5 is driven into oscillating motion, while a zone of solid boiling of the soil is formed. Amber is separated from the massif and floats to the surface under the action of the pushing force.

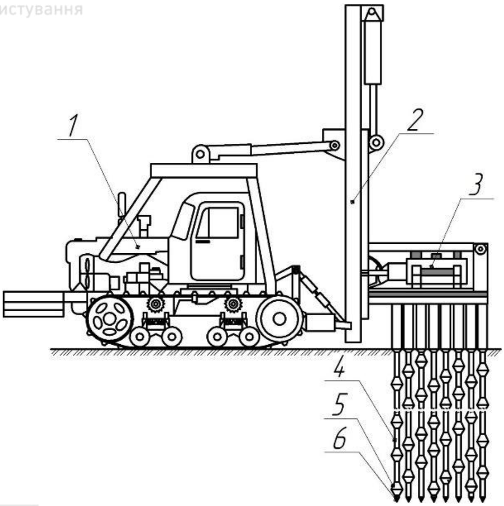

Fig. 9. Vibro-hydraulic intensifier with basic running equipment

The conical tips 6 destroy the lower layers of the soil, creating a suspension environment around them, which allows the vibrating device to move in any longitudinal direction.

Thus, the use of a vibro-hydraulic intensifier for the extraction of amber from deposits compared to other known methods (mechanical and hydraulic) has certain advantages, as it allows to achieve a high extraction of amber from the deposit, increase labor productivity, reduce energy consumption and negative technogenic-ecological impact on the environment.

Energy-efficient directions of development of the technology of extraction of amber from sand deposits

The analysis of completed research indicates that a wide range of researchers have been engaged in the study of the development of hydrocarbon extraction technologies, but differences in deposit conditions and mineral composition have prevented universal quantitative conclusions from being drawn in the research. To provide practical value to quantitative solutions, the physical assumptions underlying the analysis must be reconciled with natural conditions in the accepted units. This leads to a lack of comprehensive research on the selection and comparative evaluation of testing and development systems based on scientific methods in the necessary volume. In addition, the diversity of mineral deposits, stages of their industrial development, and operating conditions determine not only the scientific justification for the use of systems, but also the determination of their technical and economic indicators, based on which selection and comparative evaluation is carried out. Therefore, the main elements in the geotechnological system are the open locations of mineral deposits that provide access for working agents to the deposit, and the extraction of the mineral to the surface [22-23].

Thus, geotechnological methods of mining should be considered not as competing with traditional methods, but as complementary to them. These methods are advisable to use on unprofitable deposits for underground and open methods of extraction; on large deposits of relatively poor ores where significant economic effects can be obtained due to production scale; on low-power deposits and ore occurrences of rich ores, on deposits worked by traditional methods, to extract useful components from remaining intact ores and balanced ores; on dumps of balanced ores and tailings of closed and operating enterprises for the extraction of amber in the Rivne-Volyn region.

The most promising results for the development of amber deposits in the Rivne-Volyn region are based on V.Ya. Korniyenko's research, which proposed a technology for the hydromechanical extraction of amber and the corresponding equipment [3].

The dependence of the rate of amber sedimentation has not been sufficiently investigated, but some results indicate the existence of a maximum value of this parameter depending on the airflow rate and the frequency of the working element's vibration [24]. However, these results only suggest the possibility of an extremum in the case of one deposit and do not allow determining the maximum possible rate of amber sedimentation, the required airflow rate, or the justification of these parameters for other deposits.

Thus, the existing technical means for implementing the hydromechanical extraction process of amber do not fully meet the requirements, namely, the developed technologies do not guarantee the complete extraction of the useful component from the enclosing rocks and do not always efficiently utilize the working fluid. Some factors in the hydromechanical extraction technology have been overlooked by many researchers, although they determine the efficiency of hydromechanical mining facilities and the economy of resources (energy, water, and the quantity of extracted useful component).

Recommendations for calculating and justifying the parameters of energy-efficient amber mining

When using the hydro-mechanical method for amber extraction, the mass is excited by vibration and water or water and air are supplied to the mass. A working tool of the rod type is known for amber extraction, which acts on the environment through biconical vibrators that transmit harmonic oscillations. Water or water and air are supplied to the mass through the rods. Air intensifies the process of thinning the mass and allows for reducing water consumption to the volume of the pores. Thinning the mass is carried out until the density corresponds to the maximum speed of amber flotation, disregarding the gradient of filtration in the surrounding mass. In the case when the process is carried out by supplying water to the mass without air, to determine the necessary water consumption for the working process, the mass composition in a thinned state up to the required density will be studied. Based on Maslov's research, the soil mass is considered a three-phase dispersed system consisting of a skeleton, water, and gas trapped in the pores. Experimental studies on amber extraction by the hydro-mechanical method have allowed for consolidating and systematizing scientific theoretical developments and proposing a methodology for lifting amber to the surface of sand deposits.

The system approach allows for viewing an object as a system consisting of many elements connected by internal links and is a methodological principle of scientific analysis.

In many studies, processes are considered in a static state, which does not provide a complete picture of the processes occurring in the system. Therefore, research is necessary that reflects not only the physical essence of processes and phenomena occurring in the elements of the system, but also has a purpose that is associated with identifying the mechanism of loss of useful components in the dynamics and development of the system elements.

Justification and selection of rational development systems are usually the logical conclusion of the analysis and are based on the basic principles of the technical and economic evaluation of the extraction of minerals from deposits.

The use of the vibro-hydraulic method for extracting amber from amber-bearing sands allows for achieving complete extraction of amber from the deposit, increasing labor productivity, reducing energy consumption, and minimizing the negative techno-ecological impact on the environment.

The process of extracting amber using the hydro-mechanical extraction technology is presented in Fig. 10. The extraction of amber occurs in the following stages:

lifting the amber to the surface using a vibro-hydraulic intensifier with the help of vibration, water, and air supply;

collecting the lifted amber with the upper layer of the sandy environment and loading it onto a transport vehicle using loading equipment (loader, excavator, scraper);

transporting the collected amber using a dump truck to the enrichment and sorting line;

enriching and sorting the obtained mass (separating amber from sand and sorting by size classes).

The essence of the proposed technological scheme is that the mass is saturated with water and activated by mechanical stimulation (vibration) to form a continuous suspensory layer of such density that a lifting force is generated, which lifts the amber to the surface of the deposit.

The vibro-hydraulic installation (Fig. 10) is installed on a hinged base that is attached to the crane beam and carries out transportation, support and extraction from the soil massif of the installation. Air and water are supplied through pipelines through hollow cores into the soil mass. At the end of each rod is fixed a tip with cutters for destroying the soil. The rods are bundled and rigidly connected to the slab.

The process of soil liquefaction occurs as follows. Rods are immersed in the amber massif using the vibration method while water and air are simultaneously fed through them into the massif. The array is brought into oscillating motion by the oscillation of the rods, while a zone of solid boiling of the soil is formed. Amber is separated from the massif and floats to the surface under the action of the pushing force. To intensify the process of liquefaction of the soil, the air supply is turned on. Regulation of the frequency, amplitude of oscillations and forcing force is carried out by changing the frequency of rotation of the drive shaft.

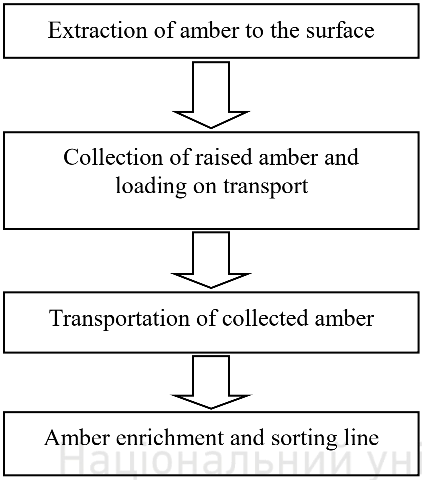

Fig. 10. Technological diagram of hydromechanical extraction of amber

The creation of the density of the medium to obtain the conditions for amber floating at maximum speed depends on the supply of the gas-liquid mixture, the parameters of oscillations, the geometric parameters of the installation and its weight. The supply of water affects the duration of dilution of the medium.

Installation movement is possible when moving the mobile equipment around the deposit. In this case, the rods remain in the sand mass, developing areas around themselves, or are extracted from the mass using a crane and repositioned to a new area for extraction.

When using cranes on wheeled equipment, paired chassis should be used to increase the wheel pressure area on the surface. Practice has also shown that mobile equipment on tracks is effective in difficult-to-pass, moist, and marshy areas. Such a climate is observed in the northern territory of Rivne region, where amber extraction takes place.

The duration of the installation's operation in one area consists of the time required for sinking, amber extraction, and rod extraction from the mass. Rational parameters of the dominant factors of amber extraction from amber-bearing sands were obtained during experimental studies: vibration exciter frequency of 26-36 Hz, density of rarefied amber-bearing medium of 1670-1750 kg/m^3, water flow rate in the mass of 0,01-0,02 m^3/hour, and air flow rate of 0,004-0,006 m^3/hour, with the lifting speed of amber reaching 0,09-0,12 m/s and the efficiency of amber extraction up to 95%. At the same time, the duration of sinking to a depth of 2 m will be within 1 minute, 2 minutes of operation, and 1 minute of excavation, so the entire process should take no more than 5 minutes. After that, the installation is transported to another area, but in such a way that the working zones of the installation intersect or touch.

After the area of the deposit has been worked out using the hydromechanical method, the collected amber with the upper layer of sand is collected using an excavator or loader and loaded onto a dump truck. The collected mass transported by dump truck is taken to the enrichment and sorting line bunker, where the amber is separated from the remaining sand medium and sorted by size classes.

To ensure efficient use of equipment for hydromechanical extraction of amber from amber-bearing sands, it is recommended to organize the operation of the installation as follows. With the help of a crane-beam wheel base, the installation is delivered to the development site. The installation is transferred from the transport position to the working condition. First, the unit is installed on the ground by lowering the slab of tie rods. The hydraulic motor that activates the vibrator is turned on. When the installation is lowered, the rods are sunk into the soil with a vibrator. The array is excited by the bars. The supply of water through the rods to the massif is turned on. The mass of cultivated soil liquefies with the formation of a solid suspension layer. Pieces of amber that are in the zone of the suspension layer are freed from bonds and float to the surface under the action of the Archimedean force and vibrational forces. To intensify the process of liquefaction of the soil, the air supply is turned on. Regulation of the frequency, amplitude of oscillations and forcing force is carried out by changing the frequency of rotation of the hydraulic motor shaft with the help of a throttle.

After that, the installation is transported to another site, but in such a way that the operation zones of the installation intersect or touch (Fig. 11).

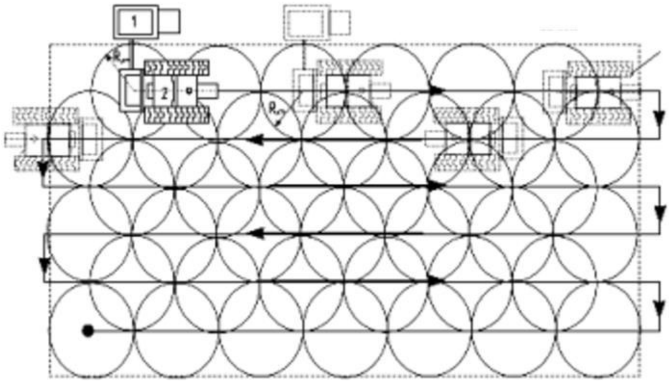

Fig. 11. Scheme of operation of the installation at the amber mining site

Thus, the use of hydromechanical extraction technology for the extraction of amber from deposits makes it possible to achieve up to 95% extraction of amber from the deposit, increase labor productivity, reduce energy consumption and negative technogenic-ecological impact on the environment. The use of the proposed technological scheme allows, after the end of amber extraction from the Earth's bowels, to continue using these areas for their purpose without carrying out reclamation.

Conclusions

The general conclusions of the study show that modern amber mining requires the use of the latest technologies and technical means, which ensure increased productivity and efficiency of mining, as well as reducing the negative impact on the environment. The introduction of the hydromechanical method of amber extraction is the most rational solution, as it does not require complex reclamation works and ensures minimal capital and operating costs.

The study also showed that the developed methods for calculating the main technological parameters and new recommendations for substantiating the parameters and technological schemes of hydromechanical extraction of amber ensure an increase in the efficiency of amber extraction, the productivity of the technology and a reduction in water consumption. Application of these techniques and recommendations can help increase the efficiency and productivity of the amber mining process, reduce its negative impact on the environment, and ensure the sustainable development of this industry.

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GAS CONTROL IN MINES OF THE KARAGANDA BASIN (REPUBLIC OF KAZAKHSTAN)

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Annotation
Subject of the study are various research works which are carried out concerning issues of degassing, ventilation, management of gas release, etc. The following methods were used for the study: analysis, generalization, experimental works. Purpose is summarizing the experience of gas emission control in complex mining and geological conditions of mines in a number of Karaganda Basin (Republic of Kazakhstan) in the work of high-productivity mines, where the level of absolute gas content reaches very high values. In conclusion of the study it should be noted the experimental work with a total duration of 5 months in four faces at three mines of JSC "ArcelorMittal Temirtau" CD showed that the allowable methane content in the outgoing jets of faces and mine sections of 1.3% creates conditions for more rhythmic and uninterrupted operation of mine sections, compared with the limit methane content of 1.0%. The use of this modern high-precision system allows continuous quality control of the mine's atmosphere and promptly and automatically cut off

electricity in areas with high methane content or violations of the ventilation mode (reduction of air supply).

Introduction

Statement of the problem of coal mining. Within the framework of the implementation of the third Program of accelerated industrial-innovative development until 2030, the mining and metallurgical complex of the Republic of Kazakhstan is assigned the role of one of the driving forces of the Republic's economic development, a major factor in the formation of macroeconomic indicators. The main task of MMS industries is to provide conditions for the structural reorganization of the national economy and the creation of new knowledge-intensive production of high-tech end products that are competitive in world markets. At the same time, the coal industry continues to play an important role in the country.

The coal industry has been one of the most important industries in many countries of the world for decades and even centuries. In recent years, the importance of this mineral for developed European countries has begun to decline due to its negative impact on the environment and the climate. The opportunity to switch to alternative energy sources has also played a role.

However, the production and use of coal continues in the global energy industry, as evidenced by the examples of leading countries in the world, such as China, the United States, India, Australia, Russia, Kazakhstan, etc., which occupy the leading position in terms of coal production in the world and year by year increase its production.

The introduction of modern innovations in the processing and use of coal can allow the transformation of coal into a relatively clean source of energy.

In the Republic of Kazakhstan, the growth in production of this type of raw materials is largely due to the needs of metallurgy. Kazakhstan is the world's ninth-largest coal producer (over 100 million tons per year).

The main directions of complex innovative scientific and technological development of underground coal mining. The main directions of complex innovative scientific and technological development of underground coal mining at the existing and newly designed mines should be based on the realities of the modern world and provide for the creation and implementation of modern innovative technologies based on the use of highly productive types of mining equipment and be safe not only technically, but also environmentally. By the example of mines in the Karaganda coal basin is particularly important problem of creating safe mining conditions for the development of high-gas content and outburst coal seams.

Priority areas in the use of modern innovative solutions and modernization of mining equipment, taking into account current trends in the development of mining production should consider the following key points:

- comply with environmental safety requirements, including the prevention of environmental pollution, zero-waste mining and processing of extracted raw materials, rational use of land with subsequent restoration, etc.;
- Ensure technical safety of mining operations and create a comfortable environment for workers and engineers;
- Ensure high productivity through the use of modern, high-performance and reliable hardware and technology, as well as other aids;
- create the possibility of wide implementation of remote control of mining equipment, as well as promote automation and robotization, with the possible use of artificial intelligence;
- Provide for the effective management of the gas environment, guided not only by the pursuit of increased productivity and personal safety of working people, but also by concerns for global environmental and climate security [1].

Highlighting an unresolved problem. In recent years, the mines of the Karaganda Basin are widely used mechanized mining complexes of foreign firms and companies (Germany, Poland, etc.), allowing to achieve high average daily loads from the working faces.

The Karaganda coal basin is one of the largest coking coal producers among the CIS countries and, at the same time, one of the most gas content basins in the world [2,3,4]. The main barrier to achieving high coal production is the high methane gas content. High loads on the face, reaching 6-8 thousand tons of coal per day from a single longwall face, became possible due to the use of modern equipment and high efficiency of methods used to control gas emission in the mines [5].

To ensure stable and high coal production and create safe working conditions in the basin, various measures are taken to reduce the gas content of seams, various methods and schemes of degassing of developed and adjacent satellite seams, as well as mined-out spaces are tested and implemented [6-10].

Choosing the unresolved part of the general problem. When mining high gas content coal seams, high loads on working faces equipped with modern coal mining equipment are accompanied by large methane emissions from the developed and adjacent seams, which significantly affects the efficiency of high-capacity clearing equipment, since the gas factor limits the productivity of the shearers. Consequently, the issues of gas emission in the mines of the Karaganda Basin is an important problem on which should conduct extensive research and experimental work.

Formulating research goals. The relevance of the issues of gas emission control is due to the fact that today's modern high-productive work of the working faces in the basin is possible through the use of integrated methods of degassing, reducing the gas content of mining areas by 70-90%, as well as the development and implementation of technical solutions to reduce the natural gas content below the critical value.

In this direction in the basin in cooperation with scientific institutes and institutions various research works are carried out concerning issues of degassing, ventilation, management of gas release, etc.

In this work, on the basis of experimental studies conducted in mining areas is summarized the experience of gas emission control in complex mining and geological conditions of mines in a number of Karaganda Basin in the work of high-productivity mines, where the level of absolute gas content reaches very high values.

Experimental work to control gas emission with a maximum methane content of 1.3% at mining section 321K10-yu of Abaiskaya mine

The 321K_{10}-yu longwall-field is located in the southern part of the Abaiskaya mine. The size of the excavation pillar along the strike - up to 695 m, and along the dip of the layer - 176 m. The bedding is gentle undulating. Seam inclination – 10-20°. Depth of development - 428-493 m. Industrial reserves of the working area amount to 725 thousand tons.

Formation K_{10} has a complex structure and is characterized by a very consistent thickness - up to 4,85 m. Useful seam thickness -

4,34 m. Extracting seam thickness - 3,9 m.

The main roof of the K_{10} formation is composed of sandstones up to 19-24.0 m thick and with a strength of up to 55-56 MPa. The immediate roof is composed of claystones 5.3-8.0 m thick, with a strength of up to 28 MPa. The ground is composed of claystone up to 3.0 m thick, with a hardness of up to 26 MPa.

Maximum gas content of the formation - up to 24.0 m3 per ton of rock mass, volatile content - 20.2%. Moisture content of the formation – up to 4,5%.

The coals of the formation are slightly fissured, predominantly semi-matte. Coal hardness on Prof. Protodiakonov's scale - up to 1,5. Formation K_{10} from a depth of 260 m is classified as dangerous by sudden coal and gas emissions.

The longwall was equipped with a 20KP-70K mechanized complex, an SL-300 combine. Cutting cross-section - 7,26 m^2.

Planned production - 3,000 tons per day. Operational coal losses at the longwall face 170 thousand tons or 21.2%.

Ventilation of the excavated area is carried out by the return-flow scheme. According to calculations, with a planned production of 3000 tons/day the following project values were assumed: the relative methane emission from the mined layer - 7.38 m^3/t, from the mined-out space - 48.26 m^3/t. Relative methane emission at the working area - 55.64 m^3/t. Absolute gas content of the area is 115.9 m^3/min. After removal of methane by degassing means, the absolute gas content of the area is 13,52 m^3/min, the air consumption at the area - 1730,0 m^3/min, in the mine working - 1331 m^3/min.

Studies of gas emission into the 321K$_{10}$ longwall face and adjacent workings

During long-term observations from December 2011 to February 2012, general data were obtained on the total methane content of the 321K$_{10}$-yu mine area in terms of methane removal from the longwall face through ventilation, as well as on methane extraction by degassing means, including vertical wells, drainage adit, degassing pipe in the upper face and formation wells [5].

According to the data collected, Fig. 1 shows graphs of daily coal production, methane extraction by means of ventilation and degassing for the above period.

As Fig. 2 shows, the daily production of coal with a plan of 3,000 tons per day, as a rule, exceeded the plan by up to 1,6 times.

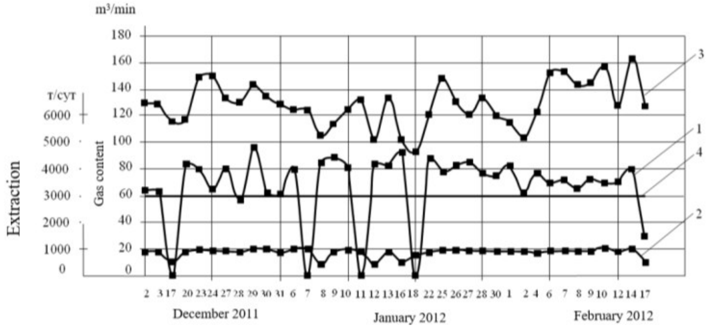

Fig. 1. Coal mining, gas content and degassing efficiency in the 321K_{10}-yu longwall of the Abaiskaya mine: *1* - coal mining; *2* - ventilation gas content; *3* - gas content: venting + degassing; *4* - planned production

According to the data obtained during the observations the general methane content of the mine area was 104.7-148.9 m^3/min, including 15-19.35 m^3/min that was extracted by means of ventilation. The largest volume of extracted methane (101-130 m^3/min when operating in production mode, and 78.1-96.2 m^3/min on Sundays) falls on degassing facilities. This extracts from the gas draining adit - 47.75-98.23, m^3/min. By means of a pipe, connected to the top face, 7.2-25.7 m^3/min were capped. The lowest gas extraction values occur on non-working days of the week. Vertical wells extract 3.49-8.06 m^3/min, and formation wells extract 4.54-9.9 m^3/min. The greatest volume of gas emissions occurs on days with high coal production (4,400-4,800 tons per day), and when there is a secondary collapse of the main roof.

At the 321K_{10}-yu face coal was mined in December 2012 when the operation level of the safety shutdowns by the ACS MA system was set at 1.0% of the volume methane content, and in January-February 2012 at 1.3% of the methane content. During the period under review, coal production ranged from 3,133 to 4,800 tons per day.

In accordance with the approved methodology, the purpose of mine experimental studies is to assess the state of the aerogas situation in the face and adjacent workings when setting the threshold of operation of protective shutdown of electrical equipment equal to 1.3% vol. CH_4.

The essence of the experimental studies in mine conditions is to determine the amount of air entering the face and the concentration of methane in the planned points of the area.

As a result of measuring the amount of air and methane content in the longwall, a large amount of data was obtained in tabular form on 8 pp. [5].

From these data it follows that during the operation of the longwall face 321K_{10}-u in January-February 2012 the methane content in the area of the working face was mainly 0.5-0.6%, at the point No. 3 (15 m from the windway) - 0.6-0.8%, at the point No. 4 (the couch at the junction of the face with the windway) - 0.6-0.9%, mainly at the point No. 5 (in the outgoing air stream) - 0.8-0.9%. On Sundays, the methane content decreased significantly and was 0.2-0.3% in the middle part of the face, at point No. 4 - 0.3-0.4%, at point No. 5 - 0.4-0.5%.

Fig. 2 shows the distribution of methane concentration in the middle part of the face along its cross section at the set points, depending on the speed of the combine.

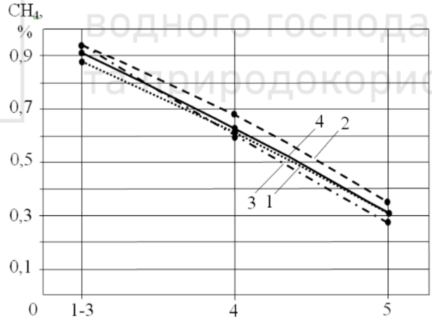

Fig. 2. Distribution of methane concentration in the middle part of the face along its cross section at the established points: *1* – at a speed of 2 m/min; *2* – at a speed of 6 m/min; *3* – at a speed of 10 m/min; *4* – average for all directions

As can be seen from the figure, with the increase in the feed speed of the combine in operating mode from 2 to 10 m/min, the methane content in the air stream increased by 0.1-0.3%. It also follows from the figure that in the air stream adjacent to the chest of the working face, the methane content is the highest and amounts to 0.8-0.95%. As methane concentration decreases to 0.2-0.4% as it moves away from the mine face toward the mined-out space. This pattern is typical for the middle part of the face along its length.

In December 2011, the system was set to a limit concentration of 1.0% outgoing air from the face and section. Figure 3 shows a fragment of the trend for the period from 19,00 h. 02.2011 till 01,00 a.m. 03.12.2011.

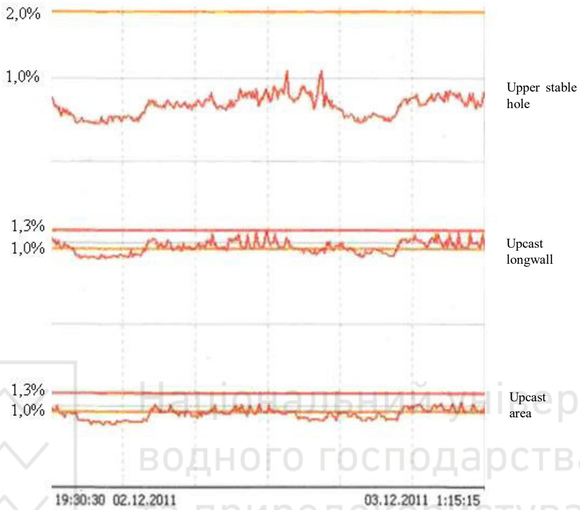

Fig. 3. Trend of methane content in the 321K10-yu mine area when sensors are installed at 1.0%

As it follows from Fig. 3, in 4 hours there were 18 registered excesses of the permissible limit of methane concentration in the air flow coming from the face and 15 in the air flow coming from the area.

This setup leads to arrhythmic operation of the shearer, a significant loss of working time and coal production due to frequent stoppages.

At the same time in the upper stable hole, due to degassing by means of a pipe, introduced into the windway, during the considered period of time there was only a small excess of methane content of 1.0% (at the permissible 2.0%).

Thus, at the limit concentration of methane in the air jets coming from the face and the area, equal to 1.0%, the rhythm and controllability of production processes are violated, which reduces the safety of production.

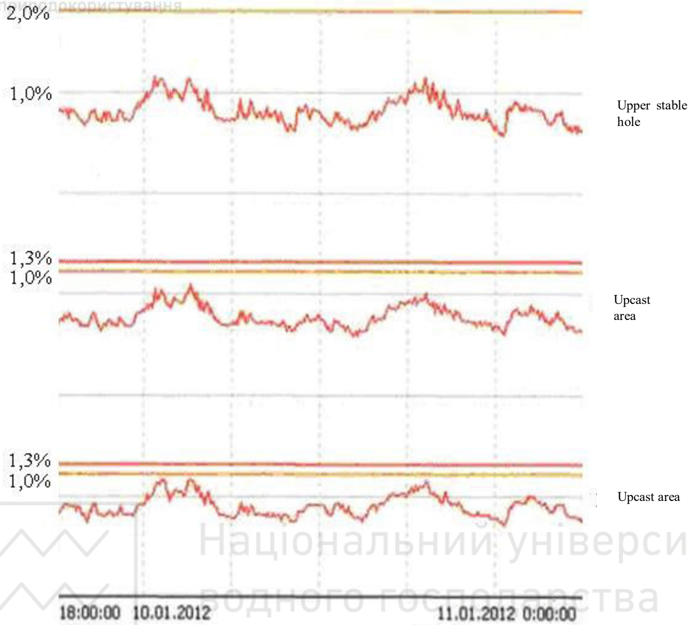

Fig. 4. Trend of methane content in the mine atmosphere of the 321K_{10}-yu mine area when setting the system thresholds to 1.3% vol. CH_4

In January 2012, the system was reconfigured at the mine area to the limit concentration of the air jet upcast from the face and the area, equal to 1.3%. Fig. 6 shows a fragment of the trend for the period from 18.00 to 24.00. 10.02.2011.

The daily load on that day was 4,420 tons. As can be seen from the presented fragment of 6 hours, during this period not a single case of exceeding the established level of methane concentration of 1.3% was recorded. At the same time, there were 4 cases of exceeding the permissible limit in the upcast air stream from the face, equal to 1.0%, and 5 cases of exceeding the permissible limit in the upcast area. Thus, the experiment allowed to establish that reconfiguring the system to the limit concentration of methane in the air jets coming from the face and the area, equal to 1.3%, allowed to provide a rhythmic and stable operation of the working face, which increased the safety of mining at the site.

In accordance with the "Methodology of experimental studies to substantiate the maximum methane concentration in the upcast air stream of the mine site" in the longwall face 321K10-yu of mine "Abaiskaya" on 12.02.2012 an experiment was made to assess the effect of air flow on changes in the methane concentration at specified points of observation (see fig. 5-7).

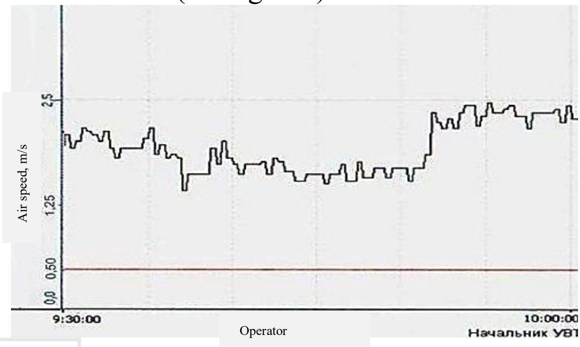

Fig. 5. Air speed in the upcast face stream 321K10-yu of Abaiskaya mine

In the course of the experiment it was found by measurements that 2167 m^3/min air was supplied to the site to ventilate it. At a certain moment the air flow was reduced to 1935 m^3/min, and then after 5 minutes the air flow was 1513 m^3/min, and in this mode the face was ventilated for another 10 minutes, after which the previous mode of ventilation was restored.

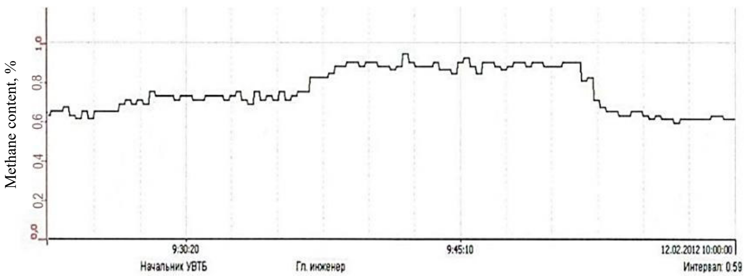

Fig. 6. Methane content in the stable hole of the longwall face 321K10-yu of Abaiskaya mine

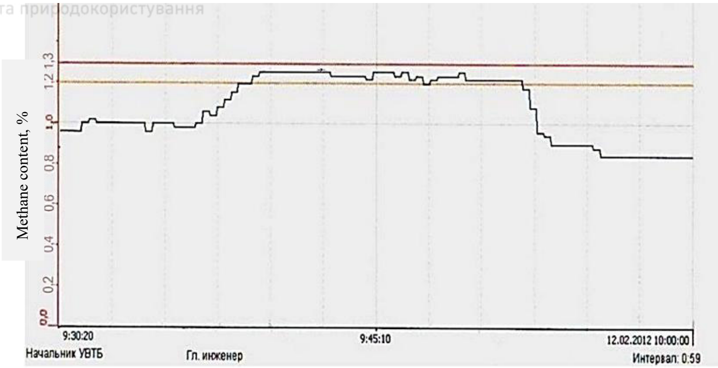

Fig. 7. Methane content in the upcast face 321K$_{10}$-yu of Abaiskaya mine

The results of measuring the amount of air supplied to ventilate the face and the methane content in the observation points are shown in Table 1.

Table 1

Results of measuring the amount of air supplied to ventilate the 321K$_{10}$-yu face and the methane content in the observation points

Measurement time, hr min		9.15	9.37	9.42	9.57
Incoming stream	air speed, m/s	2,6	2,34	1,83	2,64
	amount of air, m^3/min	2167	1935	1513	2183
Upcast stream	air speed, m/s	2,6	2,3	1,6	2,8
	amount of air, m^3/min	1850	1628	1154	1990
Methane content according to the portable device in the points, %	1	0,0	0,0	0,0	0,0
	2	0,61	0,73	0,90	0,59
	3	0,9	1,08	1,26	0,84

Recorded trends of the automated control system of the mine air (ACS MA) based on the equipment of "Davis Derby Ltd" (Great Britain) and sensors manufactured by "Wölke Industreelektronik GmbH" (Germany) are shown in Fig. 5-7 [11].

The results of the experiment showed an inverse dependence of methane concentration on the amount of supplied air for ventilation, i.e. at reducing the amount of air supplied to the face by 30% (from 2167 to 1513 m^3/min), the methane concentration in the upcast face stream increased by the same value after 1-2 minutes.

With the recovery of the previous mode of ventilation (the amount of air increased from 1513 to 2183 m^3/min) after about 1 minute, the methane content in the upcast stream of the area decreased from 1.26 to 0.84%.

A similar pattern was observed in the upper part (in the stable hole) of the face.

Thus, the experiment showed a virtually synchronous relationship between the amount of air supplied to ventilate the face and the methane content in its mine air.

Safety assessment of the mine area by the gas factor can be made by the frequency of its gassing, i.e., by the frequency of power outages established by the automated control system of the mine air (ACS MA) and by the gassing factor.

The indicator of the frequency of gassing can be considered the average number of gassings for the mine area per unit of time considered (turn, day, month).

The gassing ratio is defined as the ratio of the total downtime of mining equipment due to shutdowns by the automated control system of the mine air (ACS MA) to the working time of the mining area (turn, day, month).

The gassing coefficient can be determined by the formula

$$K_{gassy}=\Sigma T_{gassy}/T_{\mathrm{work}}, \tag{1}$$

where, ΣT_{gassy}- total downtime of mining equipment due to shutdowns by the automated control system of the mine air (ACS MA) for the considered period of time, hour; T_{work} - the considered period of the working time of the excavation area, hour; is calculated by the formula

$$T_{work}=\mathrm{N}24, \tag{2}$$

where: N – number of days of work at the mine area, units; *24* – number of hours per day.

At the 321K_{10}-yu longwall face, coal was mined in December when the operation level of protective shutdowns of electrical equipment was set at 1.0%. In 12 days, there were 226 shutdowns for a total of 1,053 minutes (17.5 hours). The frequency of gassing was 19 shutdowns per day. The gassing ratio was K_{gassy}=0,06. The average daily load for the time period considered in December was 3,544 tons.

Fig. 8 shows a histogram of the frequency of the shearer's shutdowns depending on the location of its work.

The analysis shows that the most frequent cut-offs occurred in the middle and upper parts of the longwall face (80-160 m).

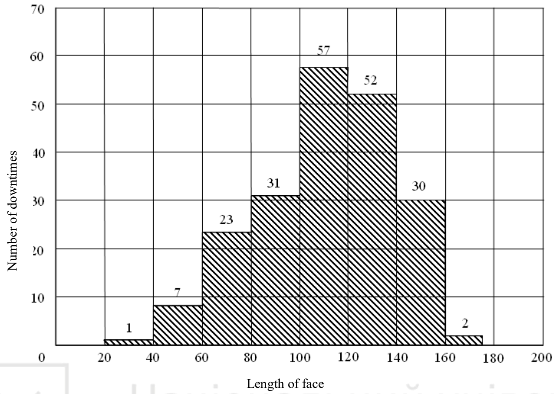

Fig. 8. Histogram of combine cut-off frequency depending on the combine's workplace in the longwall when the system operation level thresholds are set to 1.0% vol.LH_4

Experimental work at the $71K_{10}$-in working area of the Saranskaya mine

The longwall face $71K_{10}$-v was partially worked over by K_{14} seam faces in 1985-88. The distance between layers K_{10} and K_{14} is 203 m.

Total geological thickness of layer K_{10} - 4.65 m (including 3.73 m of coal mass). Extractable thickness of layer K_{10} - 3.8 m (including 3.37 m of coal mass). Adjacent strata of layer K10 is 0.4-2.3 m thick and is represented by weak claystone's of strength f=2-3, prone to collapse. Above the adjacent strata are sandstones of the main roof of strength f = 5÷6 and a thickness of 24.9-30.2 m. Sandstones of the main roof difficult to collapse. Between the adjacent and the main strata, there is a layer of siltstone with a strength of f = 3÷4 and a thickness of 3.0-3.5 m. In the ground of layer K10 there are siltstones of 6-7 m thickness and strength f=2-3 or siltstones of 6-17 m thickness and strength f=3-3,5.

The seam inclination K10 is 13-140. From the installation chamber, the excavation pillar was mined along the formation decline at an angle from 11 to 140.

Strength of coal seams *f*=0.7÷1.0, rock *f*=1.5÷2.0 on the scale of prof. Protodiakonov. The density of mined rock mass will be 1.56 t/m^3, and coal - 1.44 m^3/t.

Mining layer K_{10} is dangerous in terms of sudden coal and gas emissions.

The gas drainage entry $71K_{11}$-v along the K_{11} formation was passed at the longwall-field $71K_{10}$-v. In terms of height, the soil of the gas drainage entry is located 22-35 m above the roof of the K_{10} formation. Between the K_{10} formation and the gas drainage entry $71K_{11}$-v are sandstones of the main roof of the K_{10} formation. The method of roof control - full collapse. The pitch of the main roof is 90m.

The length of the working pillar - 1500 m. The length of the face - 176m. Depth of mining - 670 m. Balance reserves - 1178 thous. tons. Planned production of 3150 t/day.

The longwall is equipped with a mechanized support 2UKP-5, including - a shearer - SL-300, a face conveyor - KS-34. In the conveyor entry there is an overloaded PSP-308, a crusher DU-910, belt conveyors Gvarik 1000, 3LKR-1000. The cross-section of the mine working is 11.42 m^2.

Gas content of the formation under the project is 13.5 m^3/t, methane emission from the developed layer - 4.2 m^3/t, from the worked-out space - 18.4 m^3/t, including 13.34 m^3/t from six undermined layers, from three overworked layers - 0.45 m^3/t. Relative gas content of the area - 21.45 m^3/t.

The amount of air at the conveyor entry (incoming stream of the mining area) - 1890 m^3/min. Air quantity at the ventilation entry (outgoing stream of the mine area) - 1,560 m^3/min. The cross-sectional areas of the conveyor entry $71K_{10}$-v and the windway $71K_{10}$-v are 10.0 and 6.5 m^2, respectively. The air speed at the conveyor $71K_{10}$-v and ventilation $71K_{10}$-v entry is 3.15 and 4.0 m/s, respectively. Air speed along the longwall $71K_{10}$-v - 3.25 m/s.

Ventilation scheme of the mine area return-flow.

Three methods of degassing were used at the working area:

a - formation degassing by rising wells drilled along formation K_{10} from conveyor entry $71K_{10}$-v;

b - Degasification of the mined-out space by the gas drainage entry, passed through the K_{11} formation above the developed layer along the entire length of the excavation field with the possibility of connection to the mine's degasification network both ahead and behind the working face - (brattice No. 5042 and No. 5044 at gas drainage entry $71K_9$-v);

c - methane gas suction by means of a pipe set behind the bulkhead isolating the worked-out space of the worked-out longwall (brattice No. 1031 on a field-conveyor gradient $63K_{10}$-v).

d - by an isolated outlet at the expense of the general mine depression (brattice No. 25041 at the conveyor entry $64K_{10}$-v).

Study of gas emissions in the longwall face $71K_{10}$-v and adjacent workings

Methane concentrations were measured at the designated points shown in Fig. 9. Coal production ranged from 2,000 tons per day (15.01.2012) to 4,320 tons per day (11.02.2012). Air was supplied to the longwall for ventilation from 1,030 to 1,850 m^3/min.

The amount of air in the middle part of the face ranged from 950 m3/min (13.01.2012) to 1480 m^3/min (07.03.2012). The methane content in the outgoing air stream of the clearing face and the mine area according to the sensor readings was 0.5-1.2%.

General mine methane content in the mine area ranged from 74.4 m3/min (01.02.2012) to 112.55 m^3/min (24.03.2012), including ventilation means extracted from 8.4 to 21.36 m^3/min. Means of degassing extracted from 48.1 m^3/min (06.02.2012) to 79.9 m^3/min of methane (24.03.2012).

The largest volume of methane was extracted by means of drainage entry (brattice No. 5044 and 5042) from 41,1 m^3/min (06.02.2012) to 72,7 m^3/min (24.03.2012), and also by means of isolated methane drainage (brattice No. 5041) from 10,5 m^3/min (09.04.2012) to 29,06 m^3/min (30.01.2012). Minimum values of gas are extracted by means of formation degassing - 0.6 - 1.8 m^3/min. The largest volume of gas emissions occurs on days with high coal production - 4,000-4,200 tons per day.

Fig. 9 shows graphs of daily coal production and methane extraction by means of ventilation and degassing in the mine working area $71K_{10}$-v, and Fig. 14 shows a fragment of the trend of methane concentration in the mine air for the period 20.00 h. 01.03.2012 till 02.00 a.m. 02.03.2012/

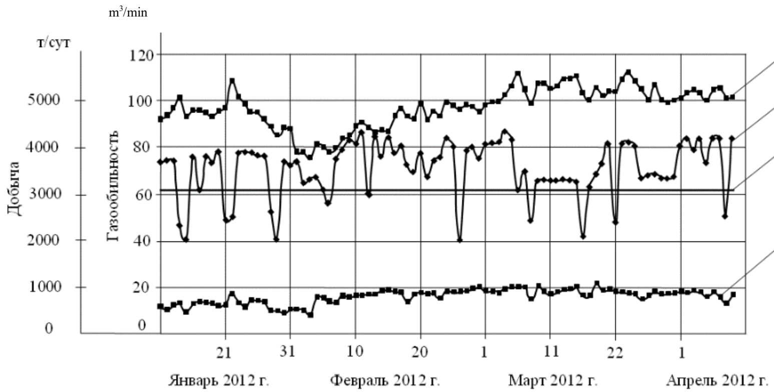

Fig. 9. Coal mining, gas content and degassing efficiency in the 71K_{10}-v longwall of the Saranskaya mine: *1* – coal mining; *2* - ventilation gas content; *3* - gas content: venting + degassing; *4* - planned production

As Fig. 10 shows, 18 methane exceedances of 1.0% in the outgoing lava air stream and 15 in the area were recorded over a period of 6 hours. Such a system setup would lead to arrhythmic operation of the shearer, a significant loss of working time and coal production due to frequent stoppages. In the upper stable hole, due to degassing by means of a pipe installed in the ventilation tunnel to be extinguished, during the period under review (at the rate of 2.0%) there was only a slight exceedance of 1.0% of methane content.

Thus, at mining of longwall face 71K10-v of mine "Saranskaya" at limiting concentration of air stream coming from the longwall face and the air stream section, equal to 1,3% and the load of the longwall face 4000-4500 tons, the combine stop for the gas factor, but when setting the sensor for the limiting concentration of air stream coming from the longwall face and the section, equal to 1.0%, the work in the longwall face would not be possible. Thus, the mine experiment showed that during the mining of seam K_{10} in the mine "Saranskaya" the most efficient operation of the shearer can be achieved when installing sensors on the outgoing from the longwall air stream to the limit content of methane equal to 1.3%.

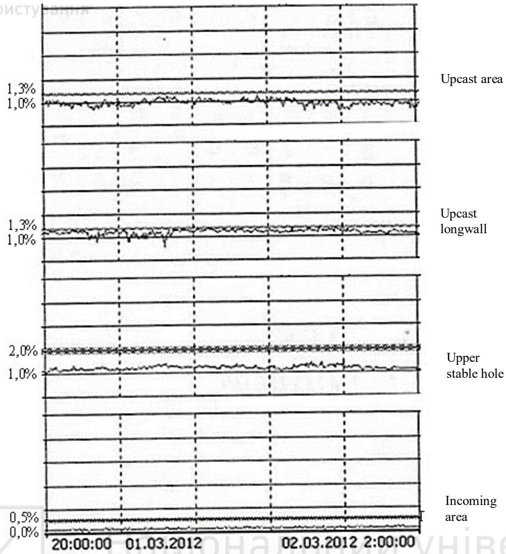

Fig. 10. Trend of methane content in the mine air of the mine area $71K_{10}$-v when setting of the system thresholds at 1,3% vol. CH_4

The safety of the working area by the gas factor can be assessed by the frequency of power outages installed by the automated control system of the mine air (ACS MA) and by the gassing coefficient.

Given the specific dynamics of outgassing in the mine's working area, despite the resolution of the permissible methane concentration up to 1.3%, the dispatcher manually stopped mining operations in the longwall at a methane concentration of 1.15%.

According to the measurements performed in the longwall face 71K10-in the period from January 11 to April 9, 2012, there were 166 manual cutoffs of power by the automated control system of the mine air (ACS MA), that is, per day there were made on average 2 cutoffs with an average duration of 16.4 minutes.

The calculations showed that if the limiting concentration of methane is taken as 1.15%, the gassing factor in the longwall face $71K_{10}$-v is K_{gassy}=0,003.

Fig. 11 shows a histogram of the frequency of the shearer's shutdowns depending on the location of its work. As can be seen from the figure, the most frequent shutdowns of the ACS MA control system mine air occurred between sections 70 and 90 of the mechanical mounts (over 37% of the total number of shutdowns). This is due to the fact that this area in the return-flow scheme is the least ventilated.

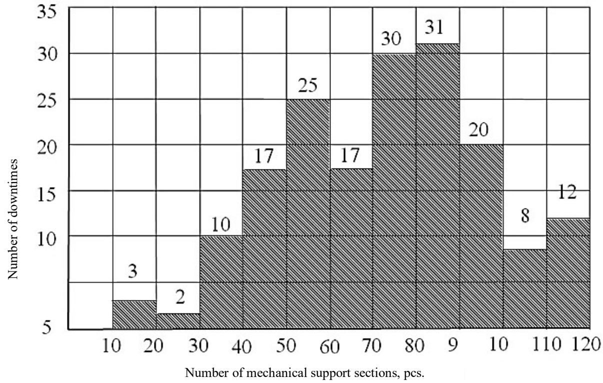

Fig. 11. Frequency of system equipment shutdowns depending on the combine's workplace in the longwall

Fig. 12 shows a histogram of the frequency distribution of failures (outages) by the ACS MA system depending on their duration. Figure 16 shows that almost half (48.8%) of all outages do not exceed 10 minutes in time, while 33.7% of outages lasted between 11 and 20 minutes. Thus, the proportion of failures with each of them lasting up to and including 20 minutes was 92.5%.

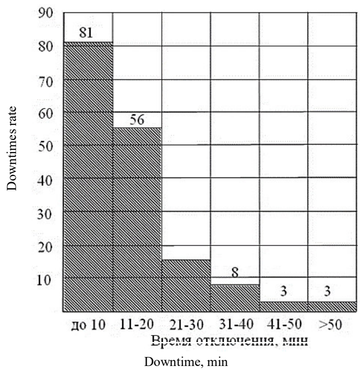

Fig. 12 . Histogram of the frequency of outages as a function of their duration

At working area $71K_{10}$-v on 03.04.2012 experimental studies of changes in the methane concentration from the amount of air supplied for ventilation were carried out. At the same time 1788 m3/min of air was supplied to ventilate the area, and 1764 m^3/min of methane concentration - 0.76% was exhausted from the longwall.

At 12 h. 08 min. air flow rate on the incoming stream was reduced to 1596 m^3/min, while on the outgoing face the amount of air decreased to 1570 m^3/min (11% reduction from the normal mode). Already after 5-7 minutes, the methane content in the outgoing lava stream has increased to 1.19. Then, at 12 h. 25 min, the amount of air on the incoming stream was reduced to 1420 m^3/min. In this mode, the amount of air on the outgoing face stream was 1100 m^3/min, i.e., decreased by 38%. Methane concentration in the longwall according to the sensor was 1.05%. In this mode the longwall was ventilated until 12 h 40 min, after which the original ventilation mode was restored.

The results of measuring the amount of air supplied to ventilate the face and the methane content in the observation points are shown in Table 2.

Table 2

Results of measuring the amount of air supplied to ventilate the 71K$_{10}$-yu face and the methane content in the observation points

Measurement time, hour, minute			11^{50}	12^{08}	12^{25}
Incoming into the longwall		air speed, m/s	3,55	2,99	2,66
		amount of air, m^3/min	1788	1596	1420
Upcast longwall		air speed, m/s	3,0	2,6	1,8
		amount of air, m^3/min	1764	1570	1100
Upcast area	windway	air speed, m	1,49	1,33	0,66
		amount of air, m^3/min	799	711	352
	cross slit No.	air speed, m	1,42	1,26	1,12
		amount of air, m^3/min	895	796	705
Methane content by sensors at points, %		1	0,0	0,0	0,0
		2	0,76	1,12	1,19
		3	0,84	1,03	1,03

The results of the experiment (see Fig. 13) showed that at reducing the amount of air supplied to ventilate the face by 11% and 21%, respectively, these values increased the methane concentration in the outgoing face stream.

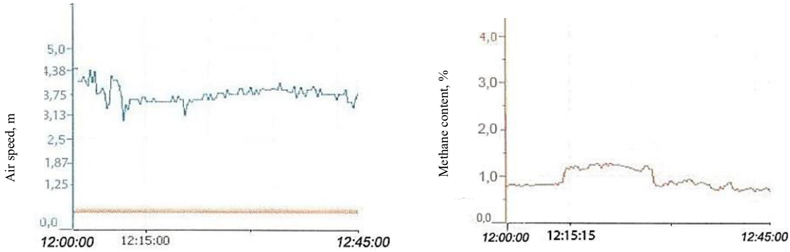

Fig. 13. Trend of air speed and methane content in the outgoing flow of the longwall of conveyor entry $71K_{10}$-v of Saranskaya mine

Experimental work at working areas $4.01D_6$-1_z and $4.02D_6$-1_z of the Lenin mine

Excavation areas $4.01D_6$-1_z and $4.02D_6$-1_z are located on the western flank of formation D_6.

Longwall face $4.01D_6$-1_z was excavated along the seam dip at the depth of 550-647 m, and the longwall face $4.02D_6$-1_z - at the depth of 567-661 m. The thickness of the layer at the section of the seam varies from 5 m at the mounting chamber to 6.5 m at the limit of the longwall stop. The average thickness of the layer is 5.8 m.

The adjacent strata are represented by mudstones and siltstones, the main roof is mainly siltstones and sandstones.

The adjacent soil of strata D_6 is represented by argillites, prone to swelling (f = 2.7) up to 1.0 m thick, and siltstones of medium hardness, with inclusions of siderite nodules (*f* = 3.5-4) slightly softened and not prone to swelling.

Formation D_6 has a complex structure and includes up to 8 interlayers of claystone and carbonaceous claystone up to 0.14 m thick. The most pronounced interlayer in the upper part of the formation is from 0.09 to 0.14 m thick, represented by weakly clayey mudstone. The remaining interlayers have a variable thickness and the ability to delineation.

The coal of the seam is prone to spontaneous combustion. Formation D_6 from a depth of 320 m is classified as especially dangerous by sudden coal and gas releases.

The natural gas content of the layer is up to 19.53 m3 per ton of rock mass, the volatile yield is 23.5%. Reservoir moisture - up to 7.0%.

Ventilation of mine workings was carried out according to the direct-flow scheme with the air stream coming from the longwall.

At longwall face $4.02D_6\text{-}1_z$, coal mining in January-April 2012 was carried out when setting the threshold for protective shutdowns of electrical equipment equal to 1.3% vol. CH_4. During the period under review, coal production was 1,360-3850 tons per day.

Studies of gas emission into the longwall face and adjacent workings

The essence of the experimental studies in mine conditions is to determine the amount of air entering the face and the concentration of methane in the planned points of the area.

During the operation of the longwall face $4.02D_6\text{-}1_z$ in January-April 2012 the methane content at point 2 (in the area of the combine operation) was 0.2-0.9% of the volume, at point 3 (15 meters from the conveyor brake incline $4.02D_6\text{-}1_z$) - 0.3-1.1%, at point 4 (in the outgoing air stream) - 0.2-1.1%, at point 5 (on the freshing air-floor) - 0.1-0.2%.

Fig. 14 shows the distribution of methane concentration in the middle part of the face along its cross section at the set points, depending on the speed of the combine.

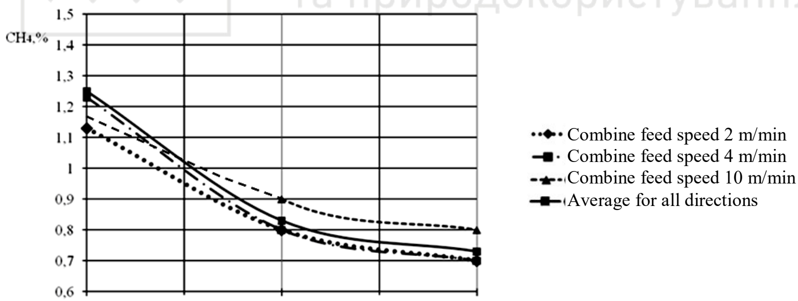

Fig. 14. Distribution of methane concentration in the middle part of the longwall along its cross section

As can be seen from the figure with an increase in the feed speed of the combine in operating mode from 2 to 10 meters per minute, the methane content in the air stream increased by 0.1-0.3%. Figure 14 also shows that in the air stream adjacent to the chest of the cleaning face, the methane content is the highest and amounts to 1.12-1.4%. With distance from the mine face toward the mined-out space, the methane concentration decreases to 0.7-0.8%. This pattern is typical for the middle part of the lava along its length.

The longwall face 4.01D_6-1_z worked only 11 days during the study period, the methane rate of the mine was 23.99 - 48.14 m^3/min, including 8.83-27.62 m^3/min that was extracted by the ventilation means. Means of degassing accounts for the following volume of extracted methane: by vertical wells - 10,76-16,19 m^3/min, by formation wells - 4,11-6,07 m^3/min.

Methane content in mine area 4.02D_6-1_z was 15.11-87.78 m^3/min, including 8.5-47.42 m^3/min extracted by ventilation means. Degassing facilities account for 2.91 to 46.31 m^3/min, including 2.0 to 16.5 m^3/min by vertical wells, 2.9 to 23.26 m^3/min in the upper casing, and 2.91 to 19.5 m^3/min by formation wells.

Figure 15 shows a graph of daily coal production, methane extraction by ventilation and degassing means for the period January-April 2012.

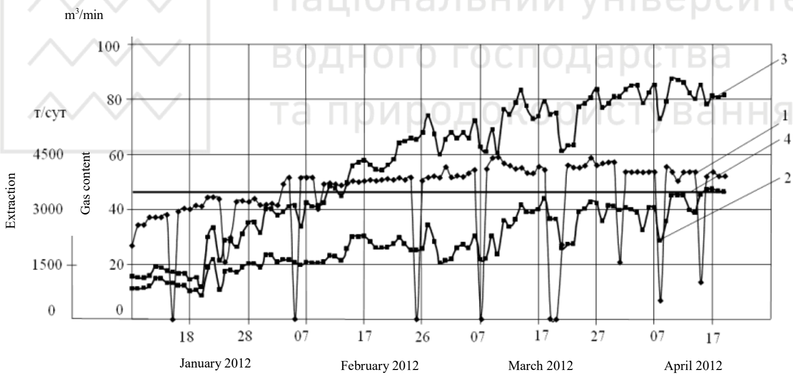

Fig. 15. Coal mining, gas content and degassing efficiency in the 4.02D_6-1_z longwall face: *1* – coal mining; *2* - ventilation gas content; *3* - gas content: venting + degassing; *4* - planned production

As the figure shows, the daily production of coal at the plan of 4,000 tons per day, as a rule, exceeded the plan by up to 1.6 times.

Since longwall face 4.01D_6-1_z worked during the study period only 11 days, only data from longwall face 4.01D_6-1_z were used for the analysis.

Fig. 16 shows a fragment of the trend on March 31, 2012 from 14:00 to 2:00 on April 1, 2012.

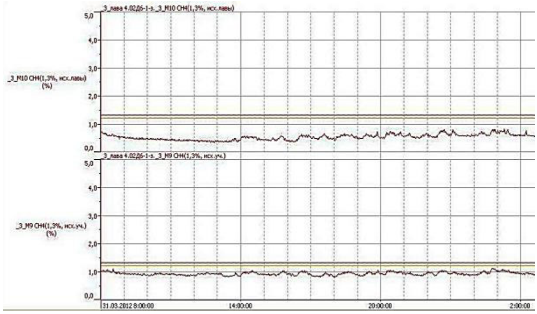

Fig.16. Trend of methane content at the outgoing face and mine area 4.02D$_6$-1$_z$

The trend fragment reflects the typical gas situation in the mine area 4.02D$_6$-1$_z$ when setting the system alarm thresholds equal to 1.3% CH_4. There were no sensor shutdowns and the shearer worked continuously. At the same time, as seen in the above fragment, setting the system to 1.0% CH_4 would result in multiple stoppages of the harvester by the gas factor.

Fig. 17 shows a fragment of the trend for February 7-8, 2012.

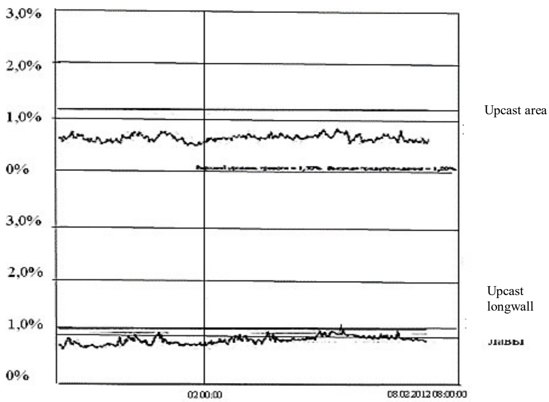

Fig. 17. Trend of methane content in the working area 4.02D$_6$-1$_z$ area with installation of sensors at 1.3%

As it follows from Fig. 17, on February 8 at 5 hours and 14 minutes there was fixed an excess (1.34% CH_4) of the permissible limit of methane concentration on the outgoing face stream. The downtime for the gas factor was 1 min.

Setting the system to the methane concentration limit in the air stream coming from the face and the area, equal to 1.3 %, allowed to provide rhythmic and steady operation of the working face, which increased the safety of mining operations at the area.

In accordance with the methodology of experimental studies, an experiment was performed to assess the impact of air flow on changes in methane concentrations at given observation points.

In the course of the experiment, measurements showed that 2,560 m3/min of air was supplied to the area for its ventilation and 1,576 m3/min for freshing.

The amount of air on the outgoing face stream was 2149 m^3/min, methane concentration - 0.73%. At 10 h 20 min, the air flow rate was reduced to 2133 m^3/min, the amount of air on the outgoing stream decreased to 1690 m^3/min, while the methane concentration on the outgoing stream was 0.79%.

Then at 10 h 40 min the air flow rate was reduced to 1712 m^3/min and to 1556 on the freshing stream. On the outgoing at this time, the amount of air was 1,319 m^3/min. Methane concentration in the longwall increased to 1.01. In this mode the longwall was ventilated until 11:00 a.m., after which the previous ventilation mode was restored.

Recording of the trends of the automated control system of the mine air (ACS MA) was performed on the basis of the equipment of "Davis Derby Ltd" (UK) and sensors manufactured by "Wölke Industrieelektronik GmbH" (Germany).

The results of measuring the amount of air supplied to ventilate the face and the methane content in the observation points are shown in Table 3.

The results of the experiment showed an inverse dependence of methane concentration on the amount of supplied air for ventilation, i.e. at reducing the amount of air supplied to the face by 38 % (from 2149 to 1319 m^3/min), the methane concentration in the outgoing face stream increased by the same value up to 5-7 minutes (from 0,73 to 1,01 %).

Table 3

Results of measuring the amount of air supplied to ventilate longwall face $4.02D_6$-1_z and methane content in the observation points

Measurement time, hour, minute		9^{50}	10^{20}	10^{40}
Incoming stream	amount of air, m^3/min	2560	2133	1712
Freshing stream	air speed, m/s	1,6	3,1	1,58
	amount of air, m^3/min	1576	3054	1556
Upcast longwall stream	air speed, m/s	3,47	2,73	2,13
	amount of air, m^3/min	2149	1690	1319
Methane content by sensors at points, %	1	0,0	0,0	0,0
	2	0,0	0,0	0,0
	3	0,73	0,79	1,01

With the restoration of the former ventilation regime (the amount of air was increased from 1,319 to 2,149 m3/min), after about 5 minutes the methane content in the upcast stream of the area dropped to 0.75%.

The results of the experiment in the Lenin mine showed a virtually synchronous relationship between the amount of air supplied to ventilate the face and the methane content in its mine air.

Conclusions

Thus, the experimental work with a total duration of 5 months in four faces at three mines of JSC "ArcelorMittal Temirtau" CD showed that the allowable methane content in the outgoing jets of faces and mine sections of 1.3% creates conditions for more rhythmic and uninterrupted operation of mine sections, compared with the limit methane content of 1.0%.

It should be noted that the maximum allowable methane content of 1.0% in the air stream coming from the longwall face was established many decades ago, when the methane content in the mine was determined by means of a gasoline lamp. The methane content was measured three times per shift. In the 1960s, gasoline lamps were replaced by gas analyzers (interferometers), through which measurements were also performed occasionally (3 times per shift), and the instruments had an error of ± 0.2% CH_4.

At present, JSC "ArcelorMittal Temirtau" CD mines have fundamentally changed the technique, procedure, and quality of methane control. All mines are equipped with the automated control system of the mine air (ACS MA).

In this case, the functions of automatic gas protection and control of the mine atmosphere are performed by sensors of methane content in the mine atmosphere and sensors of flow rate of air supplied for ventilation of workings (mining faces and dead-end workings).

Accuracy of methane concentration measurement by GMM01.04 sensors used in the mines is equal to ±0.1% of CH4 in the automatic gas control system (ACS MA).

The use of this modern high-precision system allows continuous quality control of the mine's atmosphere and promptly and automatically cut off electricity in areas with high methane content or violations of the ventilation mode (reduction of air supply).

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Based on our research results, and taking into account the experience of mines in developed coal-mining countries of the world [1], where at the current level of air control the permissible methane concentrations in the outgoing streams of mine workings have been revised to 1.5-2.0% (in the USA - 2.0%, Germany - 1.5%, Great Britain - 2, 0%, China - 1.5%, Australia - 2.0%, Ukraine - 1.3%, Russia - 1.3%), in accordance with the current level of methane concentration may be increased up to 1.3% in the outgoing streams of underground workings and working areas with reversible and direct flow ventilation schemes and automated system of continuous control of the mine air.

Acknowledgements

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DEVELOPMENT OF A CONTROL SYSTEM FOR DOWNHOLE HYDRAULIC PRODUCTION

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Abstracts

This research article contains materials on the development of an automated control system for downhole hydraulic production to achieve high technical and economic performance of the process. In recent years, the interest in the hydraulic fracturing method has increased significantly. However, the practical application of this method requires comprehensive studies of the physical and geological conditions of specific deposits, development of production techniques and designs of downhole equipment, as well as development of a mathematical model of the hydraulic fracturing process, and synthesis of a hydraulic fracturing control system based on rock erosion rate control.

Introduction

A review of existing systems showed an insufficient level of automation of the hydraulic scour process. Scour control is mainly performed by the operator, which does not provide the required quality of control and productivity. The synthesis of modern control systems for hydraulic monitoring scour requires the establishment of structural links between the input and output parameters of the object, the correct choice of controlled parameters and control actions.

In this work, it is proposed to control the process of hydraulic monitoring scouring on the basis of controlling the distance between the hydraulic monitor nozzle and the face wall and the rate of rock scouring. Monitoring the change in the size of the extraction chamber over time also provides information on the performance of the scouring process. Modern ultrasonic and laser rangefinders allow for non-contact distance measurement with high accuracy. Their hermetically sealed design and small size allow them to be used in downhole hydraulic applications.

1. Analysis of the process flow chart and existing automatic

control systems

The essence of the borehole hydraulic extraction method.

The technology of deposit development by downhole hydraulic mining is primarily related to the physical and geological conditions of the ore body. A number of natural conditions and properties of ore and host rocks (geological and hydrogeological conditions of the deposit, mechanical and hydraulic properties of ores and host rocks, etc.) have a significant impact on the parameters and mechanism of the extraction process.

Mining using borehole hydraulic extraction creates such advantages over conventional mining methods that allow for a new assessment of both known deposits and newly discovered ones. In addition, borehole hydraulic extraction provides technological, economic and environmental benefits.

Borehole hydraulic extraction of tuffs is an underground mining method based on bringing them into a mobile state at the place of occurrence by hydromechanical impact and their delivery to the surface in the form of a hydraulic mixture.

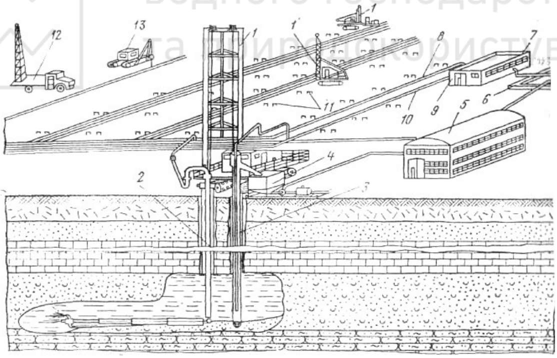


Fig. 1. Technological scheme of downhole hydraulic mining: *1* - hydraulic extraction unit; *2* - downhole hydraulic monitor; *3* - slurry lifting mechanism; *4* - dredge; *5* - processing plant; *6* - water intake basin; *7* - pumping station; *8* - water pipelines; *9* - compressor room; *10* - air pipelines; *11* - production wells; *12* - drilling rigs; *13* - pipe layers

Borehole hydraulic mining is one of the geotechnological mining methods [1], which is the most effective for the development of loose, weakly cemented ore deposits. The mineral component is extracted through specially equipped and prepared wells, with the production well being an opening, preparatory and tapping workings from which tuffs are cleaned. One of the variants of the technological scheme of downhole hydraulic production of shallow deposits through twin wells is shown in Fig. 1.

The methods of fracturing a tuff massif mainly depend on its strength. Particles of loose and weakly cemented tuffs can be detached by creating a filtration flow with the required hydraulic gradient in the formation. The most rational way to fracture cohesive rocks is to use a hydraulic water jet. The destruction process can be intensified by vibration, explosion, chemical or microbiological decomposition of the cementing agent.

The destroyed tuff is fed to the suction of the discharge device either by gravity flows (with a sufficient slope of the chamber sole) or by pressurized water flows. The hydraulic mixture is discharged to the surface using a hydraulic elevator, a submersible dredge, or by creating back pressure by injecting water or air into the deposit.

A distinctive feature of downhole equipment is the stringent conditions for transverse dimensions due to the need for its operation in the well. A hydraulic production unit (Fig. 2) is a combination of a downhole hydraulic monitor and a dispensing mechanism with a lifting and transporting part and a unit for transporting slurry from the unit [2].

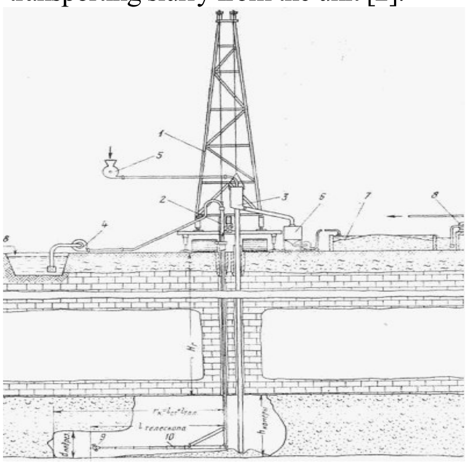


Fig. 2. Self-propelled hydraulic mining unit: 1 - lifting and transporting part of the hydraulic extraction unit; *2* - hydraulic monitor; *3* - hydraulic elevator; *4* - pump; *5* - compressor; *6* - dredge with a sump; *7* - warehouse; *8* - water supply pump; *9* - rotating hydraulic monitor head; *10* - telescopic barrel of the hydraulic monitor

The extraction process is controlled from the surface by changing the use and pressure of water, as well as the places of exposure to the working agent and selection of the useful component.

The choice of parameters of the technological process of downhole hydraulic production is determined by the geotechnological property of the useful component and the physical and geological situation [3].

The existing model of the downhole hydraulic production unit and the placement of measuring devices to control its main parameters.

Fig. 3 shows the existing automation scheme of the downhole hydraulic production process.

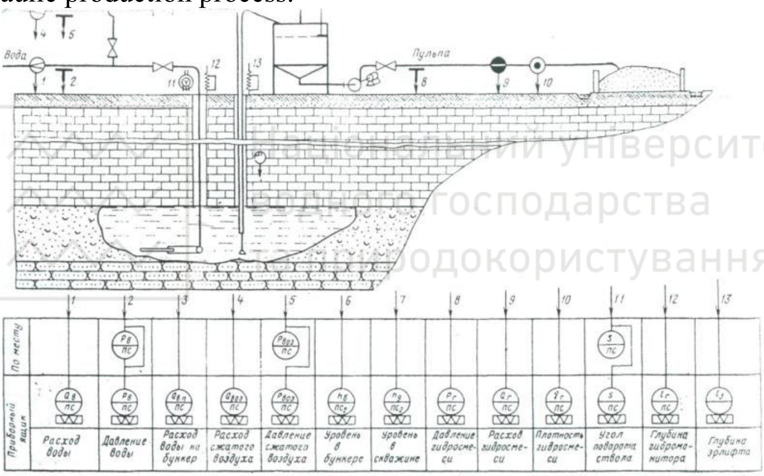


Fig. 3. Scheme of the downhole hydraulic production unit and placement of instrumentation to control its main parameters

This scheme was developed in the early 80s and is quite outdated, as it is very energy-intensive and does not control the quality of the process itself [4]. The operator's work is only partially automated. The sensors used are unreliable, with a significant measurement error, which affects the rational use of energy resources and material costs, and are "disposable" because they do not tolerate dismantling and transportation.

Equipment of production wells. Production wells to the productive horizon are drilled in the same way as conventional oil and gas wells. No curvature of the wells is allowed, which makes it difficult to lower the production tubing, especially in fractured and karstic rocks. To prevent curvature, drilling should be done with a reduced load on the bit. High mechanical drilling speed and troublefree operation can be ensured only with the correct flushing regime. Based on the results of the core study, a geological section of the well is drawn up. To study and test the core, half of it is transferred to the laboratory. After the discovery of the useful component, the well is cased and cemented. Only after the cement has hardened does drilling continue to the full extent of the deposit with a small amount of overburden.

Anchoring. The well casing process is divided into two stages:

- lowering casing;
- cementation.

Casing in the well is subjected to complex stresses (external rock pressure, internal pressure of flowing water, longitudinal tension and bending under its own weight) and, in some cases, temperature. The pipes have external threads at both ends. Cementing production wells is one of the main aspects of preparing a well for operation. Well-executed cementation outside the tubular space ensures tightness and, accordingly, the success of the well in producing the useful component. Filling outside the tubular space is performed with a conventional cement mortar.

Well pressurization. A conventional well leakage test is performed in two stages:

- testing the tightness of casing pipes;
- esting the tightness of the cementation.

The first one is performed after the cement has hardened but before the cement shoe is broken. At a shallow well depth of 100-200 meters. The casing is tested under a pressure 2-3 times higher than the pressure of the working agent during development. The second stage is carried out after the cement shoe has been broken and under the casing string. The test pressure is equal to twice the pressure of the working agent.

Before the drilled wells are equipped, it is necessary to carry out a cycle of geological and hydrogeological works to test the productive horizon. Geophysical testing of wells is mandatory to determine the physical and refine the hydrogeological characteristics of the productive formation. Since each formation has certain physical properties: electrical conductivity, hardness, radioactivity, which depend on the lithological composition of the rocks, their porosity and permeability.

Production well equipment means lowering production tubing strings into the well, specially manufactured for the production process. Each geotechnological method requires a specific production well equipment.

Calculation of flow and pressure characteristics of pumps. The characteristics of the pump show the dependence of its performance indicators (head, impeller speed, pump power) and efficiency (efficiency) on the flow rate [2,3,4]. The passport characteristics of the pump are given in its technical documentation, indicating the density and temperature of the liquid for which they were obtained, as well as the diameter and speed of the impeller. The actual performance of the pump is calculated according to the passport characteristics, taking into account changes in operating conditions (diameter and impeller speed) and taking into account the influence of the particle size distribution and fractional composition of the transported material (Table 1)

$$W = W' A_E A_F, \tag{1}$$

where W - is the actual value of the pump indicator;

W' - is the passport value of the pump's performance;

A_E - is a coefficient that takes into account changes in operating conditions;

A_F - is a coefficient that takes into account the influence of the granulometric and fractional composition of the transported material.

The calculation of the flow and pressure characteristics of centrifugal pumps pumping a hydraulic mixture of polydisperse materials of different fractions is carried out according to the following algorithms (Fig. 4, Fig. 5);

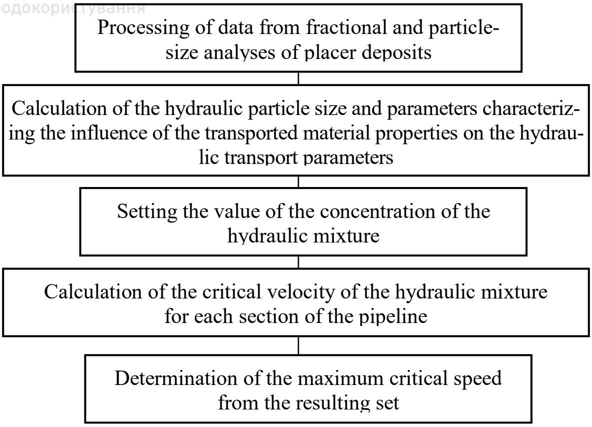


Fig. 4. Block diagram of the algorithm for calculating the critical speed for a hydraulic transport complex for hydraulic transportation of polydisperse materials of different fractions

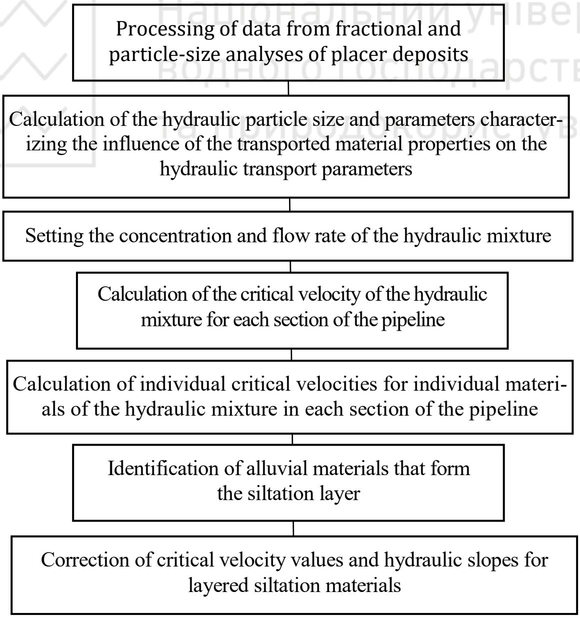


Fig. 5. Block diagram of the algorithm for calculating hydraulic slopes for a hydraulic transport complex for hydraulic transportation of polydisperse materials of different fractions

Table 1

Formulas for calculating conversion factors

Indicator	Formulas for calculating coefficients	
	A_E	A_F
Submission	$\frac{n}{n'}\left(\frac{D_p}{D'_p}\right)^{1.57}$	1
Pressure	$\left(\frac{n}{n'}\right)^2\left(\frac{D_p}{D'_p}\right)^{2.46}$	$\left(1-k_p k_z k_* \sum_{l=1}^{m}\alpha_l A_l \sum_{j=1}^{k}\psi_j k_{jl}\beta_j S\right)\rho$
Power	$\left(\frac{n}{n'}\right)^3\left(\frac{D_p}{D'_p}\right)^{3.9}$	$1+\sum_{i=1}^{3}\sum_{j=1}^{N(i)}a_j^{(i)}S_j^{(i)}$
Efficiency	$\left(\frac{D_p}{D'_p}\right)^{0.31}$	$\left(1-k_p k_z k_* \sum_{l=1}^{m}\alpha_l A_l \sum_{j=1}^{k}\psi_j k_{jl}\beta_j S\right)\rho$

The following notations are used in Table 1

$$A_l = \frac{Ar_l}{1+\sum_{i=1}^{3}\sum_{j=1}^{N^{(i)}}a_j^{(i)}S_j^{(i)}}; \qquad (2)$$

$$k_{jl} = 0.15Ar_j + 0.56\lg\frac{d_{il}}{D_p} + 1.813; \qquad (3)$$

$$k_p = 1.94 - 1.68\frac{Q}{Q_H} + 0.74\left(\frac{Q}{Q_H}\right)^2; \qquad (4)$$

$$k_z = 0.546 + 0.159z - 0.011z^2; \qquad (5)$$

$$k_* = 1.215 - 0.0077\gamma; \qquad (6)$$

$$\rho = S\sum_{l=1}^{m}\sum_{j=1}^{k}\left(1-\psi_{jl}\right)Ar_j\sigma_{jl}; \qquad (7)$$

$$\psi_{jl} = \begin{cases} 1 & k_{jl} > 0 \\ 0 & k_{jl} \le 0 \end{cases} \qquad (8)$$

where k_p - is a coefficient that takes into account the influence of the pump operating mode [4];

k_z - is a coefficient that takes into account the influence of the number of impeller blades [4];

k_* - is a coefficient that takes into account the influence of the impeller blade exit angle[4];

γ - the angle of the impeller blade exit;

z - is the number of impeller blades;

Q_H - is the nominal flow rate of the pump;

n, n' - new and passport value of the impeller speed;

D_p, D'_p - the new and passport value of the impeller diameter.

The following types of polynomials are recommended for approximating the flow and pressure characteristics of centrifugal pumps.

It is recommended to approximate the dependence of the pump head and efficiency on the flow rate with second-order polynomials

$$H(Q) = C - BQ - AQ^2; \tag{9}$$

$$\eta(Q) = E - FQ - GQ^2, \tag{10}$$

and the dependence of the pump power on the flow rate by a third- order polynomial

$$N(Q) = V + RQ + UQ^2 + XQ^3; \tag{11}$$

where *C,B,A,E,F,G are the* coefficients of approximation of the pump's flow and pressure characteristics.

Calculation of an airlift device for downhole hydraulic production of zeolite-smectite tuffs. As a rule, when calculating the airlift, the following parameters are set: hourly productivity Q, lifting height H, static or relative water level in the well h_{cm}($\alpha = \dfrac{H}{h_{cm} + H}$).

Then the purpose of the calculation is to determine the compressed air parameters and select the compressor, diameters of the air and slurrylifting pipes, and nozzle design parameters. The following calculation procedure is used for this purpose.

1. Compressed air consumption

$$V_0 = \frac{Q \cdot H \cdot \gamma'_г}{23 \cdot 60 \eta_{із} \lg\left(\dfrac{h}{w \cdot 10} + 1\right)} \tag{12}$$

where $\gamma'_г$ - is the relative density of the hydraulic mixture, kg/m^3.

$$\gamma'_г = \frac{\gamma_в}{\gamma_г};$$

$\gamma_в, \gamma_г$ - are, respectively, the densities of water and mud, kg/m^3; h - is the dynamic level in the well, m; $\eta_{із}$ - is the isothermal efficiency of the airlift:

$$\eta_{із} = \frac{H \cdot \gamma'_г}{23 \cdot q \cdot \lg \cdot \left(\frac{h}{w \cdot 10} + 1 \right)}, \tag{13}$$

where q - is the specific consumption of compressed air for lifting 1 m^3 of the hydraulic mixture, m^3/m^3.

At Q=50-300 m^3/h and H= 80-300 m, the optimal value of $\eta_{із}$ can be taken depending on the values of α

α	0,10-0,15	0,15-0,25	0,25-0,35	0,35-0,50
$\eta_{із}$	0,25	0,32	0,36	0,40

2. The diameter of the air pipe

$$d_{air} = \frac{0,000125 \cdot \beta \cdot R \cdot T \cdot G^2 \cdot l}{\Delta p p_m}, mm, \tag{14}$$

where p_m - is the average compressed air pressure in the pipe, MPa; Δp - is the pressure loss, assumed to be 5% of p_m; R - is the universal gas constant: R=29,27 kgm/kg C° (R=0,0821 atm/mol·K); T - is the average absolute temperature in a given section of the pipe T=t°C+273°K; l - is the reduced length of the air network, m, i.e. the length consisting of the actual length plus the length equivalent to the pressure losses on local supports.

The value of β, which depends on the mass flow rate of compressed air, is determined by the formula

$$\beta = \frac{2,86}{G^{0.148}}, \tag{15}$$

where G - amount of compressed air flowing, kg/h; γ - air density, kg/m^3; V - air volume at gauge pressure $V = \frac{V_0}{\rho_m + 1}$, m/h; V_0 - air flow rate reduced to normal conditions, m^3 /h, (p_0=0,10393 MPa and T_o=273K).

As a rule, at the given values of G, p_m, l_n, taking the value Δp, the diameter of the air pipe is determined by known nomograms. For an approximate determination of the diameter of an air pipe, you can use the formula.

$$d_в = 20\sqrt{V}, mm, \tag{16}$$

3. The diameter of the slurry lift pipe can be determined by the formula of V.G.Geier

$$d_e = \sqrt[2,5]{\frac{Q}{k \cdot \alpha}}, sm, \tag{17}$$

where $\alpha = \dfrac{h}{H+h}$ - is the relative coefficient of nozzle immersion under the water level; k - is a coefficient that depends on the airlift parameters.

Within the range of changes in the capacity of the elevator Q=50-300 m^3/h, the height of the lift H=100 - 300 m and at the values of α=0,20 - 0,45 the value of k is 0,24.

Then, $d_e = 1,77\left(\dfrac{Q}{\alpha}\right)^{0,4}, sm,$

4. Working pressure of compressed air

$$P_{work}=0,01(h_Д+p_1), \text{ MPa}, \tag{18}$$

where p_1 - air pressure losses in the airlift air pipe and nozzle. Usually accepted p_1=0,03-0,05 MPa.

5. Starting compressed air pressure

$$P_{start}=0,01(h_{ст}+p_1), \text{ MPa}, \tag{19}$$

6. The compressor pressure is equal to the starting pressure plus losses in the airlift p_1 and along the route p_2

$$P_с=p_{start}+\Sigma p, \text{ MPa}, \tag{20}$$

where $\Sigma p=p_1+p_2$.

7. The compressor capacity is taken on the basis of the number of lifting units and a 20% margin is given for uneven operation

$V_с=1,2\cdot\Sigma\cdot V_0$, m^3/min. (21)

The choice of size and design of the mixer is essential. Mixer designs depend on the location of the air pipe. In addition, they are both chamber type and in the form of nozzles. However, with any type of mixer, the following rules must be observed:

- the air velocity in the mixer should be 3 times less than in the duct;

- the required number of holes in the mixer or nozzle is selected so that their total area is equal to two to three live sections of the duct

$$n_{hol} = (2 \div 3) \cdot \left(\frac{d_в}{d_{hol}} \right)^2 , \tag{22}$$

where d_{hol} - diameter of the holes (d_{hol}=5-10 mm).

If the air pipe is located internally in the slurry pipe, the cross-section must be taken into account when determining the internal diameter of the slurry pipe.

2. Mathematical model of the control object

Selection of the control object. The object of control is the process of hydromonitoring scour in downhole hydraulic mining.

Rock fracturing is a key element of the downhole hydraulic production process. It involves breaking the integrity of the rock mass with a high-pressure hydraulic jet while moving the fluid mixture to the lifting device. Optimization of technological parameters and automation of the mudding process are important factors for achieving high technical and economic performance.

Due to the complexity of the processes and the variety of factors, a general theory of rock fracturing by hydraulic jet has not been developed. N.F. Tsyapko, A.M. Zhuravsky, V.S. Muchnik, M.A. Lavrentiev, V.F. Khnykin, and others made a significant contribution to the development of the theory of rock fracturing by hydraulic means.

Static and dynamic characteristics of hydromonitoring erosion. The program of experimental studies for the erosion of zeolite-smectite tuffs by a pressure water jet through nozzles with diameters of 15, 20, 25, 30 and 35 mm and a pressure of 1-3 MPa provides for the determination of productivity, maximum erosion radius, energy consumption and specific water consumption.

To conduct field studies in the basalt quarry, overlying rocks were removed from the test site to expose the mineral. The hydraulic monitor was installed at the top of the erosion sector. A trench was used as a compensatory workings to simulate the suction zone or the mouth of the outlet workings at a certain distance from the top of the sector. The research methodology was based on the time required to erode and remove a mineral with a thickness of h_n from the sector with an angle *of a*. The test was carried out in accordance with the current geological service guidelines.

The speed of movement of the hydraulic monitor's blasting nozzle along the face sector varied from 0,3 to 2,4 m/s. The rock was washed away in layers at a ledge height of 20-35 cm with the jet moving it to a boundary distance equal to the size of the scour radius. The rock removal and transportation were essentially a single process and were carried out by sequentially acting on the constantly moving face.

The transporting capacity of the jet during the erosion process significantly deteriorated with the distance of the face from the hydraulic monitor nozzle.

This was reflected in the fact that the distance over which the rocks were thrown during one cycle of the jet's impact on the face decreased, and much faster for larger fractions.

At a certain distance from the nozzle, the amount of movement of large rock fractions during one cycle of the hydraulic monitor jet impact on the face was practically zero. In the following, the scour radius will be understood as the maximum value of the distance over which the jet moves the largest rock fractions.

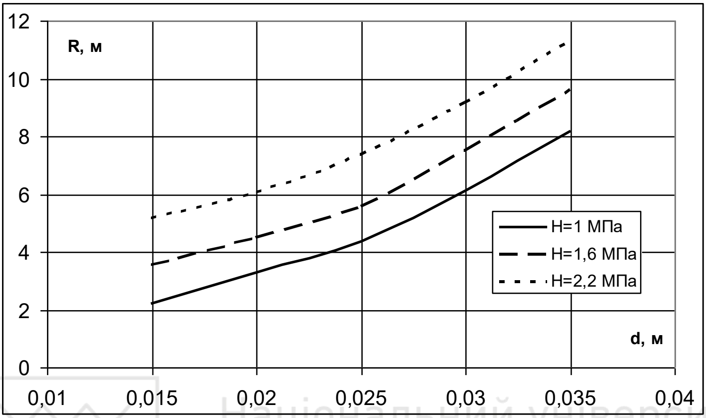
The study of the rock erosion process at different nozzle diameters and for different values of water pressure in the hydraulic monitor showed that the erosion of tuffs by jets of larger diameter leads to an increase in the radii of erosion, and with an increase in the pressure of the working agent before the nozzle, this increase becomes more significant.

Table 2

Values of the radius of erosion of zeolite-smectite tuffs by a hydraulic monitor jet

Water pressure in the nozzle	No. of experiment		Nozzle diameter *d*, m				
			0,015	0,02	0,025	0,03	0,035
H=1,0 MPa	1	The value of the scour radius R, m	2,2	3,3	4,25	6	8,1
	2		2,25	3,2	4,3	6,1	8,1
	3		2,2	3,4	4,5	6,2	8,3
	Average		2,22	3,3	4,35	6,1	8,17
H=1,6 MPa	1		3,5	4,4	5,5	7,4	9,5
	2		3,6	4,55	5,6	7,65	9,7
	3		3,5	4,5	5,6	7,5	9,7
	Average		3,53	4,48	5,57	7,52	9,63
H=2,2 MPa	1		5,1	6	7,3	9,1	11,5

2		5,3	6,15	7,45	9,2	11,6
3		5,1	6,05	7,4	9,15	10,9
Average		5,17	6,07	7,38	9,15	11,33



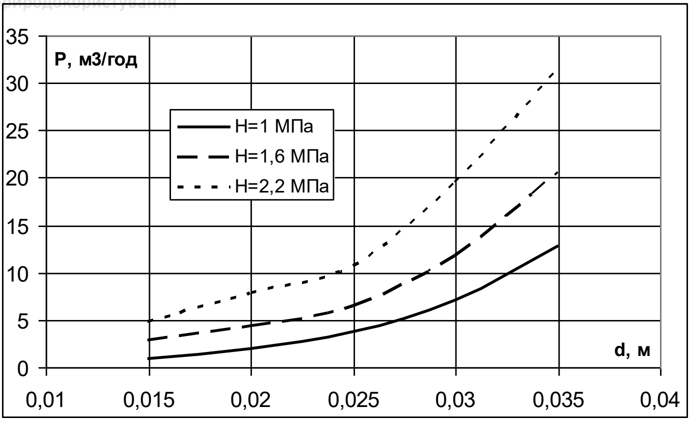
$$R(d,H) = 0{,}9e^{0{,}064d} + 2{,}5 \cdot H - 2{,}5$$

Calculation data:

The water pressure in the nozzle, *H*, MPa		Nozzle diameter *d*, m					Correlation coefficient	Standard deviation	Standard deviation %
		0,015	0,02	0,03	0,03	0,035			
1,0	R, м	2,35	3,24	4,46	6,14	8,45	0,9991	0,022956	1,03405405
1,6		3,85	4,74	5,96	7,64	9,95	0,9992	0,087642	2,4827762
2,2		5,35	6,24	7,46	9,14	11,45	0,9996	0,016402	0,31725338

Table 3

Erosion performance of zeolite-smectite tuffs P, m^3/h			
Nozzle diameter do , mm	H, MPa		
	1	1,6	2,2
0,015	0,9	2,8	4,9
0,02	1,9	4,3	7,8
0,025	3,8	6,5	10,7
0,03	7,1	11,8	19,5
0,035	12,8	20,5	31,5



$$P(d,H) = 0{,}07e^{148d} + 3{,}3 \cdot H - 2{,}8$$

Calculation data:

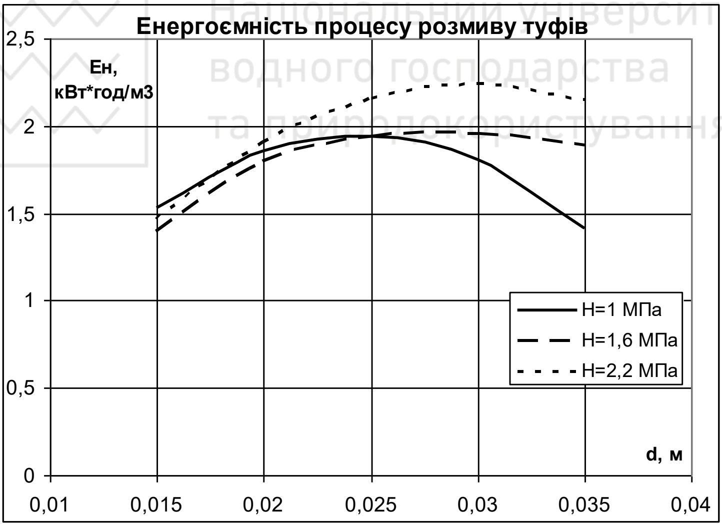
Erosion productivity of zeolite-smectite tuffs P, m /h³				
Nozzle diameter do , mm		H, MPa		
		1	1,6	2,2
Experimental data	0,015	0,9	2,8	4,9
	0,02	1,9	4,3	7,8
	0,025	3,8	6,5	10,7
	0,03	7,1	11,8	19,5
	0,035	12,8	20,5	31,5
Estimated data	0,015	1,14	3,51	5,88
	0,02	1,85	4,64	7,43
	0,025	3,33	7,01	10,69
	0,03	6,43	11,97	17,52
	0,035	12,94	22,38	31,82
Correlation coefficient		0,9967	0,9982	0,9948
Standard deviation		0,1488	0,8898	1,0270

Table 4

Nozzle diameter d, m	№ experiment	Energy intensity of the tuff erosion process En, kWh/m³		
		H=1,0 MPa	H=1,6 MPa	H=2,2 MPa
0,015	1	1,45	1,41	1,46
	2	1,55	1,36	1,41
	3	1,6	1,42	1,52

	average	1,53	1,4	1,46
0,02	1	1,9	1,75	1,91
	2	1,85	1,84	1,92
	3	1,82	1,81	1,9
	average	1,86	1,8	1,91
0,025	1	2	1,91	2,2
	2	1,95	1,95	2,15
	3	1,88	1,97	2,13
	average	1,94	1,94	2,16
0,03	1	1,79	2,01	2,22
	2	1,8	1,95	2,25
	3	1,83	1,93	2,25
	average	1,81	1,96	2,24
0,035	1	1,4	1,94	2,12
	2	1,45	1,92	2,15
	3	1,38	1,82	2,17
	average	1,41	1,89	2,15

Study of the energy intensity of the process of tuff erosion



$$\begin{cases} E_н = -ad^2 + bd - c \\ a = 3174 \cdot H^2 - 11158 \cdot H + 12755 \\ b = 134,8 \cdot H^2 - 448,1 \cdot H + 546,1 \\ c = 1,09 \cdot H^2 - 3,465 \cdot H + 3,26 \end{cases}$$

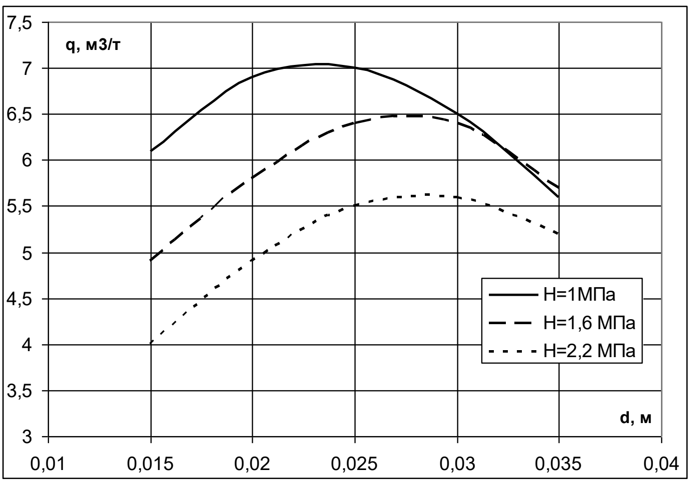
Calculation data:

Nozzle diameter d, m	Energy intensity of the erosion process En, kWh/m^3 Pressure H, MPa		
	1,0	1,6	2,2
0,015	1,53	1,43	1,47
0,02	1,86	1,77	1,91
0,025	1,95	1,96	2,17
0,03	1,81	2	2,26
0,035	1,42	1,88	2,16
Correlation coefficient	0,9997	0,992	0,9998
Standard deviation	0,00004	0,00078	0,00014
Standard deviation, %	0,003	0,056	0,01

Table 5

Value of specific consumption of the working reagent

Nozzle diameter d, m	Specific consumption q, m /t^3		
	H=1,0 MPa	H=1,6 MPa	H=2,2 MPa
0,015	6,1	4,9	4
0,02	6,9	5,8	4,9
0,025	7	6,4	5,5
0,03	6,5	6,4	5,6
0,035	5,6	5,7	5,2



$$\begin{cases} q = -ad^2 + bd - c \\ a = -1983 \cdot H^2 + 4203 \cdot H + 9209 \\ b = -174{,}2 \cdot H^2 + 525{,}3 \cdot H + 192{,}3 \\ c = -2{,}71 \cdot H^2 + 10{,}5 \cdot H - 8{,}3 \end{cases}$$

Calculation data:

Nozzle diameter d, m	Energy intensity of the erosion process En, kWh/m^3		
	Pressure H, MPa		
	1,0		1,0
0,015	6,09	4,8	3,9
0,02	6,81	5,83	4,87
0,025	6,95	6,32	5,4
0,03	6,53	6,27	5,49
0,035	5,53	5,68	5,13
Correlation coefficient	0,9966	0,9946	0,9987
Standard eviation	0,0033	0,0069	0,0076
Standard deviation, %	0,0589	0,1412	0,1895

Table 6

Dynamics of tuff destruction. Laboratory experiment on a scale model

Slaughte ring distance *l/d*	Water pressure at the nozzle inlet P_o , MPa					
	0,2		0,7	0,2		0,7
	Nozzle diameter *dн*, mm					
	4,2	6,0	4,2	4,2	6,0	4,2
	Erosion rate *V*, m/min			Blurring time *t*, min		
2	3,25	2,9	2,4	-	0	-
4	3,15	2,7	2,2	-	0,16	0
6	2,95	2,4	1,8	0	0,45	0,15
8	2,4	1,6	0,8	0,3	1	0,6
10	1,3	0,9	0,3	0,9	3,5	1,2
12	0,5	0,4	0,1	2	9,5	2,8
14	0,37	0,25	-	3,8	-	5,5
16	0,25	0,15	-	6,5	-	10
18	-	-	-	13,6	-	-

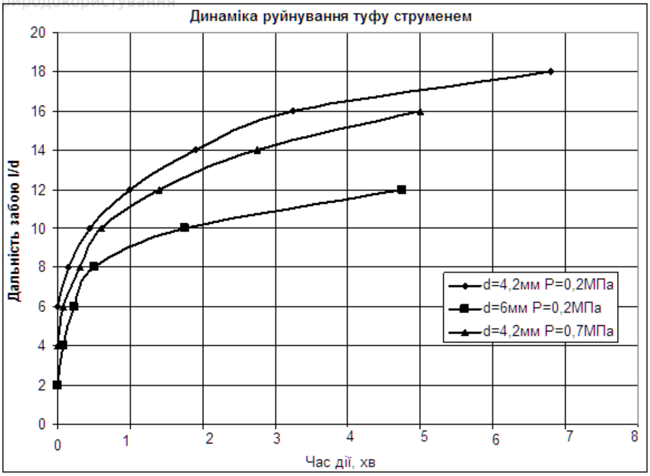


Fig. 5. Dynamics of tuff rock destruction

The approximation and statistical processing of the experimental data was carried out in MatLab and Microsoft Exel software packages. Most of the experimental data were approximated by second-order polynomials.

The polynomial approximation of the measurement data, formed as a certain vector Y at certain argument values that form a vector X of the same length as the vector Y, was performed using the built-in MatLab procedure polifit(X,Y,Z), where Z is the order of the approximating polynomial. The result of this procedure is a vector of length (Z+1) of the coefficients of the approximating polynomial [6].

The exponential approximation was performed in Microsoft Exel using the trend line addition function, which results in the construction of an approximating curve and the display of its equation on the graph of the experimental data.

To verify the reliability of the approximation and its quantitative assessment, the data were statistically processed, namely, the correlation coefficient and standard deviation between the experimental data and those calculated using the approximation dependencies were found.

The correlation coefficient was determined by the formula

$$r = \frac{\sum (x_i - x_{cp})(y_i - y_{cp})}{\sqrt{\sum (x_i - x_{cp})^2 (y_i - y_{cp})}}, \tag{23}$$

where *x*,*y* - experimental and calculated data, respectively.

The standard deviation was calculated using the formula

$$\delta = \frac{\sqrt{\sum (x_i - y_i)^2}}{n-1}, \tag{24}$$

where *n* - number of measurement points.

To quantify the reliability of the established mathematical dependencies, the maximum relative error between the experimental results and the calculated values for each measurement point was determined

$$\gamma_i = \frac{x_i - y_i}{x_i} \cdot 100\% \cdot \tag{25}$$

The dependence of the scour radius on the pressure of the working agent and the diameter of the nozzle for zeolite-smectite tuffs of the Polytsky open pit can be approximated by the following equation

$$R(d_0, H_0) = 0,9e^{0,064 \cdot d_0} + 2,5 \cdot H_0 - 2,5 \,. \tag{26}$$

The maximum relative error in calculating the rock scour radius was 9,07%.

The productivity of tuff erosion, depending on the pressure and diameter of the hydraulic monitor nozzle, is approximated by the following relationship

$$\Pi_p(d_0, H_0) = 0,07 H_0 \cdot e^{148 \cdot d_0} + 3,3 \cdot H_0 - 2,8 \,. \tag{27}$$

The maximum error in the calculation of erosion performance is 12,3%.

When deriving analytical dependencies from experimental data that are complex functions of two variables, i.e., for families of curves, an approximation dependency of a certain type was built for each curve as a function of one variable. Then, based on the values of the coefficients in the equations of these curves, graphical and approximation dependencies were built as functions of the second variable. Replacing the coefficients of the first approximation dependence with the equations of the second variable gives a function of two variables.

The dependences of the energy intensity of the tuff erosion process and the specific consumption of the working agent on the pressure and diameter of the hydraulic monitor nozzle were approximated by the following equations, respectively

$$\begin{cases} E_н = -ad_0^{\ 2} + bd_0 - c \\ a = 3174 \cdot H_0^{\ 2} - 11158 \cdot H_0 + 12755 \\ b = 134,8 \cdot H_0^{\ 2} - 448,1 \cdot H_0 + 546,1 \\ c = 1,09 \cdot H_0^{\ 2} - 3,465 \cdot H_0 + 3,26 \end{cases}, \quad (28)$$

$$\begin{cases} q = -ad_0^{\ 2} + bd_0 - c \\ a = -1983 \cdot H_0^{\ 2} + 4203 \cdot H_0 + 9209 \\ b = -174,2 \cdot H_0^{\ 2} + 525,3 \cdot H_0 + 192,3 \\ c = -2,71 \cdot H_0^{\ 2} + 10,5 \cdot H_0 - 8,3 \end{cases}. \quad (29)$$

The maximum discrepancy between the calculated and experimental data with this method of approximation is much smaller and, accordingly, is 2,14% for determining the energy intensity of erosion and 2,5% for the specific flow rate.

Mathematical model of the object. The results of experimental studies of the dynamics of rock fracture under the influence of a water jet are shown in Fig. 5.

The figure shows that at small distances between the hydraulic monitor nozzle and the face wall, rapid rock destruction occurs. As the distance between them increases, the pressure on the face wall decreases and when it reaches a critical value, rock destruction stops.

The above dependencies are well described by a differential equation with an initial condition

$$\begin{cases} T(l_{P0}, P)\dfrac{dl_P(t)}{dt} + l_P(t) = K(P, l_{P0}) \cdot P(\mathrm{t}) \\ l_P(0) = l_{P0} \end{cases}, \quad (30)$$

where l_P - the scouring distance; P - water pressure in the nozzle; $K(P, l_{po})$ - transmission coefficient; $T(l_{po}, P)$ - time constant; l_{P0} - initial distance from the nozzle to the face wall.

Thus, the process of hydraulic fracturing is a complex object in which the parameters K, T depend on the conditions of the process (pressure in the nozzle, physical and mechanical parameters of the rock, jet flow environment, distance from the nozzle to the face wall, shape and size of the nozzle, etc. From experimental studies, it was found that the time constant T under the existing technological conditions varies within 28-33 s. Therefore, to simplify the modeling, we take the time constant equal to T=30 s, which will not significantly affect the modeling results. The transmission coefficient K changes significantly and depends on two parameters and should be taken into account in the modeling.

Applying the Laplace transform to the equation, we obtain the transfer function of the object

$$W(s) = \frac{K(P, l_{po})}{T(l_{P0}, P) \cdot s + 1} \tag{31}$$

By modeling in MatLab/Simulink, the transient characteristics of the object in terms of range and scour rate were obtained (Fig. 6) at a pressure of P=1 MPa, l_{P0}= 0.55, K=1 m/MPa, T=32 s.

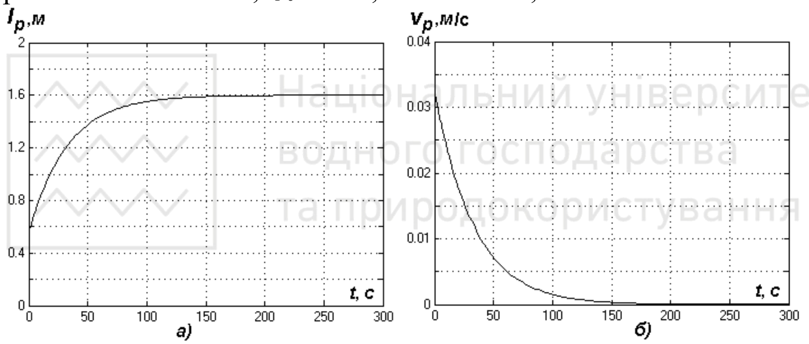


Fig. 6. *a* - Transient response of the object in terms of scour distance; *b* - transient characteristic of the object by scour rate

3. Development of an automatic control system

Selection and justification of control coordinates and control actions. A review of existing systems has shown an insufficient level of automation of the hydraulic scour process. Scour control is mainly carried out by the operator, which does not provide the required quality of control and productivity. The synthesis of modern control systems for hydraulic monitoring scour requires the establishment of structural links between the input and output parameters of the object, the correct choice of controlled parameters and control influences.

The efficiency of erosion is determined by the performance of the hydraulic monitor and specific energy consumption, which depend on the parameters of the jet, physical and mechanical properties and structure of the mineral being mined, the magnitude of forces and pressures in contact with the face, and technological methods of rock erosion.

The controlling influences during hydraulic monitoring are the pressure and flow rate of the working agent (water), the speed of rotation and movement of the telescopic hydraulic monitor nozzle in the face.

The need for pressure management stems from a number of reasons:

- ressure control is essential to ensure the efficiency of the washing process and energy savings. Insufficient pressure results in a sharp decline in productivity. Excessive pressure creates a cut in the rock, resulting in a decrease in efficiency;

- excessive pressure scatters eroded rock around the chamber, making it difficult to transport;

- At the optimum pressure value, conditions are created to produce pulp with a certain rock fraction required for its efficient transportation and lifting;

- pressure control at short distances from the nozzle to the face wall prevents blockage of the transportation channel. The complexity and conditions of the underground hydraulic fracturing process make it difficult to monitor the process parameters.

Development of a control algorithm for hydraulic scouring. In order to control the HFD process technology in the optimal mode, it is necessary to rationally select methods and means of controlling its main parameters.

When analyzing downhole hydraulic production processes as an automation object, all process equipment can be divided into two groups. The first group includes compressor, pumping, etc. equipment for which standard schemes and levels of automation have been developed and are used.

The second group includes production equipment of the SGV (downhole hydraulic monitor, airlift, hydraulic elevator), for which there are practically no developed automation schemes.

When creating an automation project, it is necessary to establish structural relationships between input (control) and output (controlled) parameters, select methods and means of registering and transmitting information to control points, take static and dynamic characteristics of objects and determine their type as an automation object, develop and implement automation schemes, and set the required frequency of measurement and data transmission.

The controlling parameters of the hydraulic monitor are the pressure and flow rate of power water in the nozzle, as well as the speed of rotation and feeding of the nozzle into the face. The output (estimated) parameters are the density of the hydraulic mixture and its flow rate, which determine the productivity of the solid component.

The input parameters of the hydraulic elevator are the pressure and flow rate of working water, and the output parameters are the hydraulic elevator's hydraulic mixture capacity.

One of the existing variants of the fundamental structural scheme of automated control of hydraulic demolition equipment is an interconnected control system. The productivity of hydraulic destruction is regulated by changing the pressure of power water depending on the density of the hydraulic mixture measured after the dredge by a density meter. The comparative device of the pressure regulator (PR) receives signals from the pressure and density sensors of the hydraulic mixture (MH), as well as the water pressure setpoint. The PT regulator processes the received signals and generates a control signal to the actuator sleeve, which regulates the pressure of the power water.

According to the above-described existing scheme, the hydraulic monitor is controlled manually, depending on the density of the hydraulic mixture after airlift. As experience is gained and rock fracture patterns are established, it is necessary to switch to automatic control of the hydraulic monitor using programmable logic controllers.

We propose a strategy for the automatic control of the technological process of the LPG based on the mathematical apparatus of fuzzy sets. The advantage of the fuzzy logic approach over classical methods in describing control systems is that it is possible not to use analytical dependencies, but a professional description of how the process is controlled by an experienced operator is sufficient. At the same time, solving this problem by means of classical theory is quite a challenge, and creating an accurate mathematical model is too complicated.

Complex systems are successfully managed by experienced operators based on qualitative process analysis. Such operator control is based on intuitive rules such as "if...then", which are not fully quantified.

Fuzzy logic makes it possible to store and process inaccurate information. This approach emerged objectively because as control systems become more complex, the ability to make accurate and meaningful statements about the system's behavior decreases and the point is reached at which accuracy and meaningfulness become mutually exclusive characteristics.

The main procedure of fuzzy logic is the fuzzy inference procedure, which is used to obtain an approximate solution from fuzzy conditions. The fuzzy inference procedure is based on the operation of logical inference (implication). Implication allows you to formalize a knowledge base according to the rules "if X, then U where X - premise, U - conclusion. In the case of fuzzy control, X - base set of values of x of the controlled variable; U - base set of controls u.

Depending on the method of obtaining logical conclusions from fuzzy rules, there can be different types of controllers. For industrial use, we propose the Mamdani fuzzy controller algorithm, when the controller generates a clear unambiguous control based on the defuzzification procedure. The general structure of a fuzzy logicbased controller consists of a fuzzification unit, a knowledge base, a decision-making unit, and a defuzzification unit.

The phasing unit converts the current input clear values into fuzzy values expressed by linguistic variables. The phasing variables are flow rate F, power water pressure P, and pressure change ΔP.

Each linguistic variable is described by a membership function. In this case, each numerical value of the process variable is associated with the degree of membership in the fuzzy subset that symbolizes a particular linguistic variable. For example, the numerical range of pressure P is characterized by the linguistic values "Low", "Medium" and "High".

For the formation of fuzzy control influences in the block of logical decision formation, fuzzy conditional rules laid down in the knowledge base are used. The knowledge base has the form "F=...AND P=...,THEN ΔP=...". For example, "IF F="Large" AND P="High", THEN ΔP ='Reduce". In this case, the rules are formulated in such a way that the result is achieved when at least one of the rules is acceptable for any linguistic variable.

In the defuzzification block, the fuzzy data obtained in the decision block is transformed into a clear, specific value that is used to influence the control object. There are various methods of defuzzification. We use the center of gravity method to calculate the control influence.

$$\Delta P = \frac{\mu_{\text{decrease}} P_{\min} + \mu_{\text{increase}} P_{\max} + \mu_{\text{unchanged}} 0}{\mu_{\text{decrease}} + \mu_{\text{increase}} + \mu_{\text{unchanged}}}, \qquad (32)$$

where

$\mu_{\text{decrease}}, \mu_{\text{increase}}, \mu_{\text{unchanged}}$ - membership functions for management.

According to the described algorithm, the fuzzy controller is realized by a program written into the permanent memory of the programmable logic controller.

The use of a fuzzy algorithm to control technical objects ensures:

- Reducing the fluctuation of the controlled value;
- maintaining the controlled parameters at the minimum tolerance level, which reduces energy consumption;
- the ability to use this algorithm for various objects without prior mathematical research.

The operating conditions for monitoring and control equipment in SAGM production are rather unfavorable. Process sensors and power cables are installed outdoors and are exposed to the weather. Frequent moves from one well to another (as they are developed) complicate their installation. Most sensors are subject to hydro-abrasive wear, which significantly increases their failure rate and, accordingly, operating costs, so it is necessary to provide for increased redundancy conditions when designing. For receiving and transmitting information from several similar GHG installations, it is economically feasible to have one set of telemechanics receiving and transmitting equipment in the central control room (CR).

Nowadays, with the rapid development of science and technology, many tasks of human activity are becoming complex and cumbersome and require an accurate mathematical description to solve them. Sometimes, when it is possible to solve such a problem using classical theory, the mathematical models created are too complex and require a lot of time and effort to create. The implementation of such models increases the requirements for technical support, and due to their complexity, the number of calculations is rapidly increasing, which in turn leads to a decrease in the performance of the system as a whole.

At the same time, complex systems are successfully managed by experienced operators based on qualitative process analysis. Such operator control is based on intuitive rules such as "...if...then", which are not fully quantified.

It is the experience and way of thinking of an expert operator that is intended to be used in a new direction of control systems and system approach called Fuzzy logic. Fuzzy logic is one of the most promising areas of modern control theory. Currently, this theory is experiencing a real upswing all over the world.

Expert systems are a likely area for the implementation of fuzzy logic algorithms, including expert systems:

- non-linear process control (production);
- self-learning systems;
- research of risks and critical situations;
- Pattern recognition;
- financial analysis (securities markets);
- data research (corporate repositories);
- improving management and coordination strategies. For example, complex industrial production.

Classical or Boolean logic has a significant drawback: it cannot be used to describe associative thinking. It operates with only two concepts: TRUE and FALSE, and excludes any intermediate values.

The basis of fuzzy logic is the theory of fuzzy sets, where the function of an element's membership in a set can take any value in the range 0-1. The whole range of logical operations is provided for such values: union, intersection, negation, etc. Fuzzy logic makes it possible to build knowledge bases and expert systems of a new generation that can store and process inaccurate information. This approach has emerged objectively because as control systems become more complex, the ability to make accurate and meaningful statements about the system's behavior decreases and the line is reached where accuracy and meaningfulness become mutually exclusive characteristics. The author of the theory of fuzzy sets, the American mathematician L. Zadeh, stated: "...as complexity increases, exact values lose significance, and significant statements lose precision".

The general structure of the fuzzy logic-based controller is shown in Fig. 7. and consists of:

- phasing unit;
- knowledge base;
- decision-making unit;
- defuzzification unit.

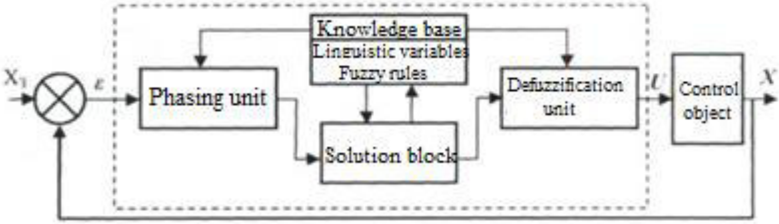


Fig. 7. General structure of the fuzzy controller

The fuzzification unit converts the current input crisp values into fuzzy values, which are expressed by linguistic variables. Each linguistic variable is described by a membership function. Each numerical value of a process variable is assigned a degree of membership in the fuzzy subset that symbolizes a particular linguistic variable.

To generate fuzzy control influences, the logical decision-making unit uses fuzzy conditional *"if"*-*"then"* rules laid down in the knowledge base. The "*if* part (precondition) can mean the conjugation of any complexity of logical operations. The *"then"* part (decision. conclusion) is the definition of a linguistic variable for the output value of the controller. In this case, the rules are formulated in such a way that a result is achieved in which at least one of the rules is acceptable for any linguistic variable.

In the defuzzification block, the fuzzy data obtained in the decision block is converted into a clear value that is used to influence the control object.

Controlling the process of hydraulic monitor washout by speed. In existing systems, the hydraulic monitor is controlled by operating time and pulp consistency. This choice of controlled parameters does not allow for effective process control for a number of reasons:

- since the pulp density measurement is carried out on the surface, there is a large transportation delay;
- he eroded rock is raised to the surface by airlifts or hydraulic el-

evators, the efficiency of which decreases when the consistency of the pulp changes;

- the change in pulp consistency is also affected by the settling of eroded rock during its transportation to the lifting mechanism.

We propose to control the process of hydraulic monitoring scouring on the basis of controlling the distance between the hydraulic monitor nozzle and the face wall and the rate of rock scouring. Monitoring the change in the size of the extraction chamber over time also provides information on the performance of the scouring process. Modern ultrasonic and laser rangefinders allow for non-contact distance measurement with high accuracy. Their hermetically sealed design and small size allow them to be used in downhole hydraulic applications.

Modeling of the scour rate control system. The block diagram of the modeling of the scour rate control system is as follows:

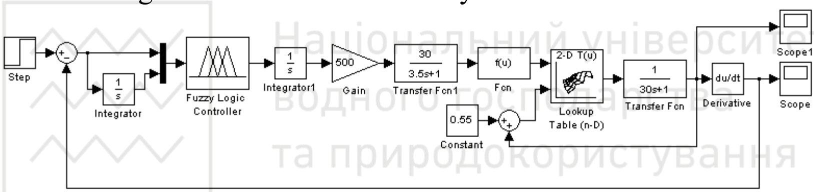


Fig. 8. Mathematical model of the scour rate control system in downhole hydraulic production

Step - input task of the speed control loop.

Integrator + Fuzzy logic controller is a fuzzy PI controller. It is customized by the operator based on previous experience.

Integrator 1 - integrating link to ensure the astatism of the system (ensuring zero error in the steady-state mode).

Gain is a frequency converter.

Transfer fcn 1- transfer function of the induction motor.

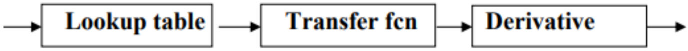
Fcn - piston pump, the output is pressure.

Constant - setting the initial distance from the nozzle to the face wall (0,55 m is the initial distance from the hydraulic monitor nozzle to the face wall).

Lookup table - block for approximating the nonlinear transmission coefficient *K* depending on the inlet pressure and the distance from the nozzle to the face wall.

Scope – output by the scour velocity V_p, m/s.

Scope 1 – object output in terms of blurring distance L_p, m.
- object of regulation.



The method of defuzzification of the fuzzy controller is Centroid (calculation of the center of gravity of the figure).

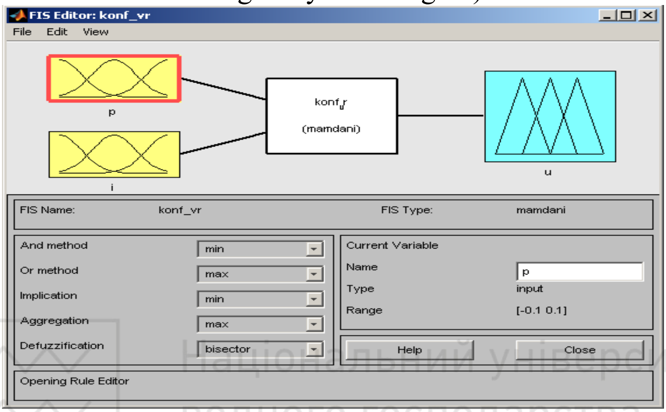


Fig. 9. Fuzzy controller of the scour rate control system

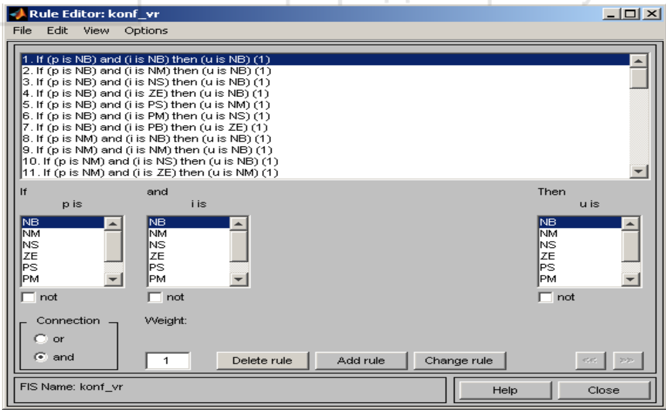


Fig. 10. The rule base of a fuzzy controller.

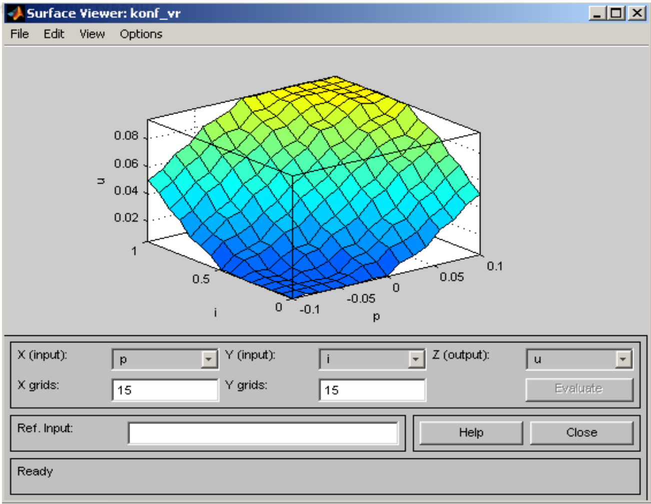


Fig. 11. Erosion rate control surface

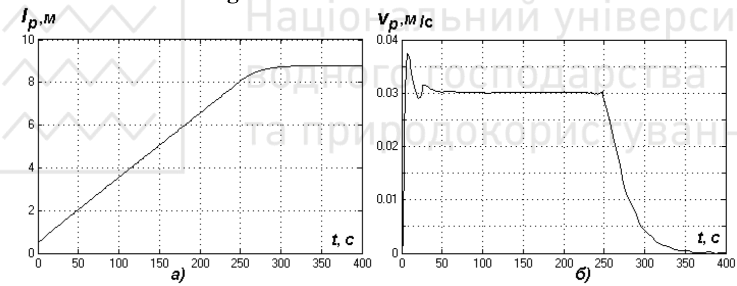


Fig. 12. *a* - transient response of the ATS by scour range;
b -transient response of the ATS by scour rate

The organization of the control process by the speed and range of erosion will ensure reliable and efficient control over the process of hydraulic monitoring erosion.

The developed mathematical model of the object can be the basis for the design of flexible control systems for the process of hydraulic monitoring scour using adaptive, extreme, self-tuning and fuzzy control methods, which will allow them to be used for the extraction of various minerals.

4. Implementation of the proposed automation system

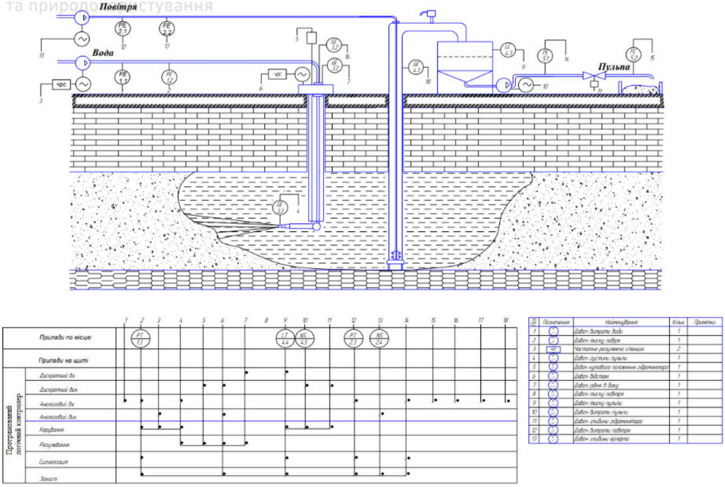


Fig. 13. Functional diagram of hydraulic scour automation

The functional diagram of the automation (Fig. 13) shows the following control, management and measurement circuits:

1. The signal from the water flow sensor is input to the analog input and is used to account for the water used, which is necessary for the technical and economic analysis of the process.

2. The signal from the water pressure sensor is input to the analog input, which is also the main parameter for controlling the pump pressure. In the event of an emergency, an alarm is triggered and a signal is simultaneously sent to the protection, i.e. the entire system stops until the problem is corrected.

3. The pressure measurement at the outlet of the pump with the frequency control station is used to supply water to the hydraulic monitor. The signal is input to the analog input and is used to regulate the hydraulic scouring process. When a signal is received from the distance sensor and the water pressure sensor, the controller sets the necessary task for the frequency control station to create the required pressure by the pump.

4. Distance sensor, which is the main indicator of the performance of the hydraulic monitor and at the same time an indicator of the balance of all regulatory bodies (2,3,5,6,7,8).

5. The signal from it is fed to the analog input, and is used for regulation and control (2,3,5,6,7,8).

6. The hydromonitor's telescope position sensor, the signal from which is input to the discrete output and to the control, i.e., regulates the telescope extension length based on the distance sensor 4.

7. Frequency control station of the hydraulic monitor angle reducer. It is designed for sectoral rotation of the hydraulic monitor barrel. The signal is sent to the analog input and to the control. Also, when the protection is activated, this device stops.

8. The hydraulic monitor rotation angle sensor, the signal from which is fed to the gearbox to rotate the hydraulic monitor to a certain sector of the scour. It is connected to a digital input and directly to the control.

9. Distance sensor from the hydraulic monitor nozzle to the eroded rock. The signal from this sensor is input to the analog input and interconnected with (4,5,6,7).

10. The pulp level sensor in the hopper. It is used to regulate the level of pulp in the hopper and control the dredge pump 10 and valve

11. The signal from the sensor is sent to a discrete input and control. The sensor is also connected to the protection system of the entire system, which is triggered by an alarm, for example, when the hopper is overfilled.

12. A dredge used for pumping pulp from the hopper to the sump. The signal from which is driven to the discrete output and to the control. That is, the dredge is switched on only after the maximum signal of the level sensor 9, and off after the minimum signal.

13. A valve used to prevent the dredge from flooding. The signal from this valve is input to the digital output and connected to the control of devices 9 and 10.

14. Air pressure sensor, the purpose of which is mainly to prevent accidents in the air supply pipeline. The signal from which is sent to the analog input. When the alarm is triggered, the protection is activated and the entire system stops.

15. A compressor station designed to provide air of a certain pressure (1-6 atm) to the elevator. The signal is connected to an analog output and a protection system. Moreover, the station itself also contains a protection system, which is connected to the protection system of the entire scour system.

16. Slurry pressure sensor, the signal from which is connected to the analog input, alarm and protection system. The main task of this

device is to prevent pressure overload in the pipeline from the hopper to the settling tank.

17. The pulp flow sensor, the signal from which is fed to the analog input. The main task is to record the extracted pulp, which is necessary for the technical and economic analysis of the process.

18. Depth sensor of the hydraulic monitor - for controlling the height position.

19. Air flow sensor - required for technical and economic analysis of the process.

20. Airlift depth sensor - for controlling the height position.

Conclusion

The efficiency of erosion is determined by the performance of the hydraulic monitor and specific energy consumption, which depend on the parameters of the jet, physical and mechanical properties and structure of the mineral being mined, the magnitude of forces and pressures in contact with the face, and technological methods of rock erosion.

The controlling influences during hydraulic monitoring are the pressure and flow rate of the working agent (water), the speed of rotation and movement of the telescopic hydraulic monitor nozzle in the face.

The need for pressure management stems from a number of reasons:

- Pressure control is essential to ensure the efficiency of the washing process and energy savings. Insufficient pressure results in a sharp decline in productivity. Excessive pressure creates a cut in the rock, resulting in reduced efficiency;

- Overpressure scatters the eroded rock around the chamber, making it difficult to transport;

- At the optimum pressure value, conditions are created to produce pulp trol at small distances from the nozzle to the face wall prevents bwith a certain rock fraction required for its efficient transportation and lifting;

- Pressure conlockage of the conveying channel.

The complexity and conditions of the underground hydraulic leaching process make it difficult to monitor process parameters. In the existing systems, the hydraulic monitor is controlled by the operating time and pulp consistency. This choice of controlled parameters does not allow for effective process control for a number of reasons:

- Since the pulp density measurement is carried out on the surface, there is a large transportation delay;
- The eroded rock is raised to the surface by airlifts or hydraulic elevators, the efficiency of which decreases when the consistency of the pulp changes;
- The change in pulp consistency is also affected by the settling of eroded rock during its transportation to the lifting mechanism.

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STRESSED – DEFORMED STATE OF DAM FOUNDATIONS MADE OF SOIL MATERIAL WITH A TRAPEZOIDAL TRANSVERSE PROFILE

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Abstract

The mining complex is a dangerous source of environmental destruction and environmental pollution. This is especially evident in the case of large-scale mining operations.

Typical technogenic landscapes were formed in the course of open and underground mining of coal, uranium, alumina, iron ore and other mineral deposits in the territories of Donetsk, Lugansk and other regions of Ukraine, where mining and ore-dressing enterprises are located. The markers of such landscapes are the presence of heaps, dumps, industrial waste dumps, sludge pits and other sources of environmental pollution.

It is no coincidence that extractive industries are often areas of ecological disaster. The specifics of the impact of the mining complex depends on the method of extraction (open or closed), the resource being mined, and the natural features of the territory where the extraction takes place. The following main directions of the impact of extractive industries on nature and humans are distinguished:

- damage to land, the formation of anthropogenic landforms;
- change in the water balance of the territory;
- dusting of the atmosphere associated with blasting during open pit mining;
- change in the entire landscape, the formation of so-called technogenic landscapes, characterized by the almost complete absence of soil cover, vegetation, and microorganisms.

Under the conditions of Ukraine, the greatest harm to the environment is caused by the enterprises of the coal industry. The main factors of the coal industry that affect the state of the environment include:

- withdrawal from circulation of lands, their pollution with waste from coal mining and enrichment;
- depletion of water resources and changes in the hydrological regime of ground and surface waters;
- pollution of underground and surface water bodies by industrial and domestic wastewater from enterprises and settlements;
- pollution of the air basin with solid and gaseous harmful substances during the extraction, processing and combustion of solid fuels (numerous boiler houses, smoking rock dumps, etc.).

One of the ways to solve the water problem of extractive regions is the construction of artificial reservoirs, the main element of which is dams. At the same time, dams made of soil materials are most widely used. The research materials presented in this paper are aimed at solving the problem of calculating and designing reservoir dams from soil materials.

Introduction

Currently, soil dams are used for recreation in mining regions, for communications, electricity production, etc. In addition, they are used for the needs of agriculture (for example, for the construction of reservoirs).

However, when designing soil dams on foundations made of weak soils, such problems sometimes arise:

1. Sometimes the subsidence of dams is of the same order as their height [1,2,3]. In this, it is necessary to know the subsidence of the base of the dam not only in its center, but also the subsidence of characteristic points along its entire sole. This is important in order to achieve compliance of the dam profile with its design state, taking into account base deformations.

2. Foundations of soil dams made of weak soils have low strength. Therefore, it is necessary to be able to assess the strength of soil foundations of soil dams. This assessment can be carried out only if the properties of the soil and acting stresses in the base are known [1,2,3,4].

3. The profile of soil dams usually has a trapezoidal shape. In addition, usually the dam includes elements with different specific gravity (usually it is the soil of the dam body and its core) [3,4,5,6,7]. Therefore, the load on the base differs from that shown in fig. 1 and fig. 2.

Also, in [1,3,4], the coefficient of attenuation of additional stresses along the depth (using it to calculate the vertical normal stresses along the depth of the foundation) is given in tabular form only for a load having a rectangular shape (in analytical form in regulatory documents, these data are also not presented).

There are very general and approximate instructions in this regard in the construction regulations currently in force in Ukraine and other countries regarding the accounting of the specified factors [1,2,3,4,5, 6,7,8].

A similar picture occurs in the scientific and technical literature devoted to this problem [9,10]. The theses set forth in this paragraph (i.e. in paragraph 3) allowed us to conclude that the use of construction standards in force on the territory of Ukraine leads to an insufficiently accurate calculation of the stresses acting on the foundation due to the weight of the dam.

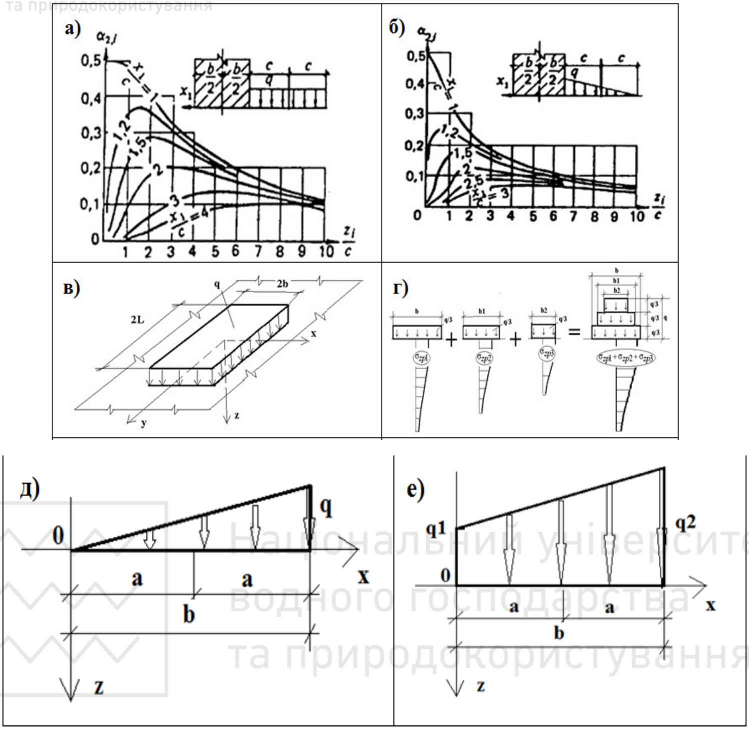

Fig. 1. The types of loads used to determine stresses in soil foundations are listed in regulatory documents and technical literature: *а* and *б* - loads on the base considered in [3,4]; *в* - the same, in [1,2]; *д* - and *е* - the same, in [10]

4. Recently, the finite element method has become widely used to predict the stress-strain state of soil foundations [11,12]. However, in this case, the calculation results are significantly affected by the dimensions of the calculation area of the base. Since there are no instructions on this matter in the regulatory documents of Ukraine, the data obtained during the forecast of the stress-strain state of the foundations of soil dams require verification and, if necessary, correction.

Therefore, when writing this monograph, we aimed to find a solution to these problems by constructing accurate analytical dependences of stresses on the coordinates and the trapezoidal external load applied to the upper limit of the base.

Application of trapezoidal vertical load

Currently, the following types of loading are used to determine the stress-deformed state of foundations of soil dams (fig. 1), the use of which is not always possible to solve the problem we mentioned. Therefore, the research task was formulated as follows:

1. An unfavorable case of a stressed - deformed state of the foundation - a dam made of soil material, the length of which is significantly greater than its width and height (fig. 2) is considered.

2. The transverse profile of the dam has the form of a trapezoid. At the same time, there may be materials with different specific gravity within the dam (for example, the core and body of the dam).

3. The pressure from the weight of the dam on the base is equal to the product of the specific gravity of its material by a height equal distance from the sole of the dam to the day surface of the dam at the vertical.

Necessary:

1. Within the framework of the model of a linear elastic isotropic medium, the conditions of plane strain and the one presented in fig. 2 loads to obtain accurate analytical solutions necessary

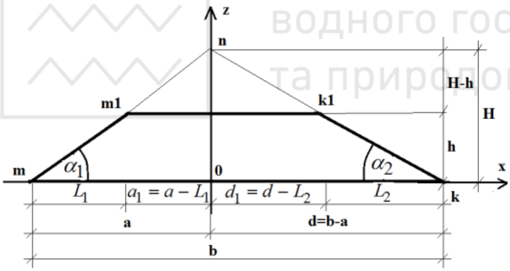

Fig. 2. Determination the geometric dimensions of the soil dam and the load on the base from its weight for determining the stressed-strained state of soil dams

Notes:

1. Bold lines indicate the outline of dam, and thin lines indicate auxiliary structures.

2. In fig. the following designations are accepted: - *h*- height of the dam, - *b* - width of the base of the dam; b_1 - dam crest width; α_1 and α_2 - the laying angles of the left and right slopes of the dam, respectively.

3. To develop an algorithm that allows taking into account the heterogeneity of the materials from which they are made when determining the subsidence of the foundations of soil dams.

4. Develop an algorithm that allows you to take into account the heterogeneity of the structure of the soil layer when determining the subsidence of soil dams.

5. Develop an algorithm that allows you to simultaneously take into account the factors outlined in paragraphs 1 and 2.

At the first stage, the research task was formulated as follows. A trapezoidal vertical load is applied to the foundation. At an arbitrary point of the base with known coordinates, it is necessary to determine the stresses caused by this load.

To solve the problem, we used the one presented in fig. 2 scheme of the profile of the dam, using which the triangular diagram of contact pressures can be transformed into a trapezoidal load.

To do this, it is necessary to present the parameters of the dam contour in an analytical form. We have:

1. The coordinate of any point of the triangle mnk can be calculated using the formula

$$Z_{mnk}(x) = H \cdot \left\{ \left(1+\frac{x}{a}\right)\left[U(x+a)-U(x)\right] + \left(1+\frac{x}{d}\right)\left[U(x)-U(x-d)\right] \right\} \tag{1}$$

Here H,a and d see diagram in fig. 2, and $U(x)$ - Heaviside step function [13].

2. The coordinate of any point of the m_1nk_1 triangle on the height interval $z \in (0, H-h)$ can be calculated using the formula

$$Z_{m_1nk_1}(x) = (H-h) \cdot \left\{ \left(1+\frac{x}{a_1}\right)\begin{bmatrix} U(x+a_1)- \\ -U(x) \end{bmatrix} + \left(1+\frac{x}{d_1}\right)\begin{bmatrix} U(x)- \\ -U(x-d_1) \end{bmatrix} \right\} \tag{2}$$

Here H,h,a_1 and d_1 - see the diagram in fig. 2.

3. Using the scheme in fig. 2 and formulas (1) and (2) we find the coordinate of any point of the trapezoid mm_1k_1k.

We have

$$\begin{gathered} Z_{mm_1k_1k}(x) = Z_{mnk}(x) - Z_{m_1nk_1}(x) = \\ = H \cdot \left\{ \left(1+\frac{x}{a}\right)\left[U(x+a)-U(x)\right] + \left(1+\frac{x}{d}\right)\left[U(x)-U(x-d)\right] \right\} - \\ -(H-h) \cdot \left\{ \left(1+\frac{x}{a_1}\right)\begin{bmatrix} U(x+a_1)- \\ -U(x) \end{bmatrix} + \left(1+\frac{x}{d_1}\right)\begin{bmatrix} U(x)- \\ -U(x-d_1) \end{bmatrix} \right\} \end{gathered} \tag{3}$$

4. In order to determine the load on the base from one meter of the length of the soil dam, (3) should be multiplied by the specific weight of the dam material $\gamma_{пл}$ and 1 meter. We have

$$q(x) = \gamma_{пл} \cdot \left[Z_{mnk}(x) - Z_{m_1nk_1}(x) \right] =$$

$$= \gamma_{пл} \cdot H \cdot \left\{ \left(1 + \frac{x}{a}\right)\left[U(x+a) - U(x)\right] + \left(1 + \frac{x}{d}\right)\left[U(x) - U(x-d)\right] \right\} -$$

$$-\gamma_{пл} \cdot (H - h) \cdot \left\{ \left(1 + \frac{x}{a_1}\right)\begin{bmatrix} U(x+a_1) - \\ -U(x) \end{bmatrix} + \left(1 + \frac{x}{d_1}\right)\begin{bmatrix} U(x) - \\ -U(x-d_1) \end{bmatrix} \right\} \quad (4)$$

To determine the dependence of the stresses acting at the base of the dam on the coordinates, we will use the well-known fundamental solution of Flaman about the vertical concentrated force applied to the horizontal upper limit of the infinite half-plane and the principle of superposition (fig. 2).

According to [14] we have

$$\left.\begin{aligned} \sigma_z(x,z) = \frac{2 \cdot z^3}{\pi} \cdot \int_{x_1}^{x_2} \frac{q(\xi) \cdot d\xi}{r(x,z,\xi)^4}; \quad \sigma_x(x,z) = \frac{2 \cdot z}{\pi} \cdot \int_{x_1}^{x_2} \frac{q(\xi) \cdot (x-\xi)^2 \cdot d\xi}{r(x,z,\xi)^4}; \\ \tau_{xz}(x,z) = \frac{2 \cdot z^2}{\pi} \cdot \int_{x_1}^{x_2} \frac{q(\xi) \cdot (x-\xi) \cdot d\xi}{r(x,z,\xi)^4}; \quad r = \sqrt{(x-\xi)^2 + z^2}. \end{aligned}\right\} \quad (5)$$

Here $\sigma_x(x,z)$ and $\sigma_z(x,z)$- normal stresses acting in the direction of the 0x and 0z axes respectively; $\tau_{xz}(x,z)$ - tangential stresses in the plane 0xz; $q(x)$ - load on the day surface of the base.

First, we will find the distribution of vertical normal stresses $\sigma_{z,\mathrm{mnk}}(x,z)$ at the point of the base with coordinates (x,y) from the one presented in fig. 2 load, distributed over a triangle mnk.

To do this, in formula (1), we replace the variable x with the variable ξ, substitute the expression obtained in this way into the upper formula (5) and perform the integration procedure on the interval from x_1=-a to x_2=d.

We have

$$\left.\begin{aligned} \sigma_{z,mnk}(x,z) = \gamma \cdot H \cdot \left[\begin{aligned} \frac{-x+d}{\pi \cdot d} \cdot arctg\left(\frac{-x+d}{z}\right) + \\ + \frac{x+a}{\pi \cdot a} \cdot arctg\left(\frac{x+a}{z}\right) - \frac{d+a}{\pi \cdot a \cdot d} \cdot x \cdot arctg\left(\frac{x}{z}\right) \end{aligned} \right]; \\ d = b - a. \end{aligned}\right\} \quad (6)$$

Next, we will find the distribution of vertical normal stresses $\sigma_{z,m1nk1}(x,z)$ at the point of the base with coordinates (x,y) from the one presented in fig. 1 load distributed over a triangle m_1nk_1.

To do this, in formula (2), we replace the variable x with the variable ξ, substitute the expression thus obtained in the upper left formula (5) and perform the integration procedure on the interval from x_1=-a to x_2=d_1.

We have

$$\left.\begin{array}{l}
\sigma_{z,m_1nk_1}(x,z)=\gamma\cdot(H-h)\left[\begin{array}{c}
\dfrac{-x+d_1}{\pi\cdot d_1}\cdot arctg\left(\dfrac{-x+d_1}{z}\right)+\\
+\dfrac{x+a_1}{\pi\cdot a_1}\cdot arctg\left(\dfrac{x+a_1}{z}\right)-\\
-\dfrac{d_1+a_1}{\pi\cdot a_1\cdot d_1}\cdot x\cdot arctg\left(\dfrac{x}{z}\right)
\end{array}\right]; \\
\qquad\qquad d=b-a.
\end{array}\right\} \qquad (7)$$

The dependence of the vertical normal stress $\sigma_z(x,z)$ on the coordinates can be found as the stress difference $\sigma_{z,mnk}(x,z)$ and $\sigma_{z,m1nk1}(x,z)$. We have

$$\left.\begin{array}{l}
\sigma_z(x,z)=\sigma_{z,mnk}(x,z)-\sigma_{z,m_1nk_1}(x,z)= \\
=\gamma\cdot H\cdot\left[\begin{array}{c}
\dfrac{-x+d}{\pi\cdot d}\cdot arctg\left(\dfrac{-x+d}{z}\right)+\\
+\dfrac{x+a}{\pi\cdot a}\cdot arctg\left(\dfrac{x+a}{z}\right)-\dfrac{d+a}{\pi\cdot a\cdot d}\cdot x\cdot arctg\left(\dfrac{x}{z}\right)
\end{array}\right]- \\
-\gamma\cdot(H-h)\left[\begin{array}{c}
\dfrac{-x+d_1}{\pi\cdot d_1}\cdot arctg\left(\dfrac{-x+d_1}{z}\right)+\\
+\dfrac{x+a_1}{\pi\cdot a_1}\cdot arctg\left(\dfrac{x+a_1}{z}\right)-\dfrac{d_1+a_1}{\pi\cdot a_1\cdot d_1}\cdot x\cdot arctg\left(\dfrac{x}{z}\right)
\end{array}\right]; \\
\qquad\qquad d=b-a.
\end{array}\right\} \qquad (8)$$

If the cross section of the soil dam has the shape of an isosceles trapezoid, then d=a, d_1=b_1, b=$2\cdot a$ and b_1=$2\cdot a_1$, where

$$\left.\begin{array}{l}\sigma_z(x,z)=\dfrac{\gamma\cdot H}{\pi\cdot a}\cdot\left[(x+a)\cdot arctg\left(\dfrac{x+a}{z}\right)-2\cdot x\cdot arctg\left(\dfrac{x}{z}\right)+\right.\\ \left.+(a-x)\cdot arctg\left(\dfrac{a-x}{z}\right)\right]-\dfrac{\gamma\cdot(H-h)}{\pi\cdot a_1}\cdot\left[(x+a_1)\cdot arctg\left(\dfrac{x+a_1}{z}\right)-\right.\\ \left.-2\cdot x\cdot arctg\left(\dfrac{x}{z}\right)+(a-x)\cdot arctg\left(\dfrac{a-x}{z}\right)\right];\quad b=2\cdot a.\end{array}\right\}\quad(9)$$

Similarly, we will find normal horizontal stresses $\sigma_x(x,z)$. We have

$$\left.\begin{array}{l}\sigma_x(x,z)=\\ =\gamma\cdot H\cdot\left[\begin{array}{l}-\dfrac{z}{\pi\cdot d}\cdot\ln\left(z^2+(-x+d)^2\right)-\dfrac{z}{\pi\cdot a}\cdot\ln\left(z^2+(x+a)^2\right)+\\ +\dfrac{z\cdot(d+a)}{\pi\cdot d\cdot a}\cdot\ln\left(x^2+z^2\right)+\dfrac{-x+d}{\pi\cdot d}\cdot x\cdot arctg\left(\dfrac{-x+d}{z}\right)+\\ +\dfrac{a+x}{\pi\cdot a}\cdot arctg\left(\dfrac{x+a}{z}\right)-\dfrac{d+a}{\pi\cdot d\cdot a}\cdot x\cdot arctg\left(\dfrac{x}{z}\right)\end{array}\right]-\\ -\gamma\cdot(H-h)\left[\begin{array}{l}-\dfrac{z}{\pi\cdot d_1}\cdot\ln\left(z^2+(-x+d_1)^2\right)-\dfrac{z}{\pi\cdot a_1}\cdot\ln\left(z^2+(x+a_1)^2\right)+\\ +\dfrac{z\cdot(d_1+a_1)}{\pi\cdot d_1\cdot a_1}\cdot\ln\left(x^2+z^2\right)+\dfrac{-x+d_1}{\pi\cdot d_1}\cdot x\cdot arctg\left(\dfrac{-x+d_1}{z}\right)+\\ +\dfrac{a_1+x}{\pi\cdot a_1}\cdot arctg\left(\dfrac{x+a_1}{z}\right)-\dfrac{d_1+a_1}{\pi\cdot d_1\cdot a_1}\cdot x\cdot arctg\left(\dfrac{x}{z}\right)\end{array}\right];\\ d=b-a;\quad d_1=b_1-a_1.\end{array}\right\}\quad(10)$$

If the cross section of the soil dam has the shape of an isosceles trapezoid, then $d=a$, $d_1=b_1$, $b=2\cdot a$ and $b_1=2\cdot a_1$. Therefore, in this case, the stress $\sigma_x(x,z)$ is equal

$$\left.\begin{array}{l}\sigma_x(x,z)=\\ =\gamma\cdot H\cdot\left[\begin{array}{l}-\dfrac{z}{\pi\cdot a}\cdot\ln\left(z^2+(-x+a)^2\right)-\dfrac{z}{\pi\cdot a}\cdot\ln\left(z^2+(x+a)^2\right)+\\ +\dfrac{2\cdot z}{\pi\cdot a}\cdot\ln\left(x^2+z^2\right)+\dfrac{a+x}{\pi\cdot a}\cdot arctg\left(\dfrac{x+a}{z}\right)-\\ -\dfrac{2\cdot x}{\pi\cdot a}\cdot arctg\left(\dfrac{x}{z}\right)+\dfrac{a-x}{\pi\cdot a}\cdot x\cdot arctg\left(\dfrac{a-x}{z}\right)\end{array}\right]-\end{array}\right\}\quad(11)$$

$$\left.\begin{array}{l} -\gamma\cdot\left(H-h\right)\left[\begin{array}{l} -\dfrac{z}{\pi\cdot a_1}\cdot\ln\left(z^2+\left(-x+a_1\right)^2\right)-\dfrac{z}{\pi\cdot a_1}\cdot\ln\left(z^2+\left(x+a_1\right)^2\right)+ \\ +\dfrac{2\cdot z}{\pi\cdot a_1}\cdot\ln\left(x^2+z^2\right)+\dfrac{a_1+x}{\pi\cdot a_1}\cdot arctg\left(\dfrac{x+a_1}{z}\right)- \\ -\dfrac{2\cdot x}{\pi\cdot a_1}\cdot arctg\left(\dfrac{x}{z}\right)+\dfrac{a_1-x}{\pi\cdot a_1}\cdot x\cdot arctg\left(\dfrac{a_1-x}{z}\right) \end{array}\right]; \\ b=2\cdot a;\quad b_1=2\cdot a_1. \end{array}\right\} \quad (11)$$

In a similar way, we will find the tangential stresses acting in the base $\tau_{xz}(x,z)$.We have

$$\left.\begin{array}{l} \tau_{xz}\left(x,z\right)=\gamma\cdot H\cdot\left[\dfrac{\left(d+a\right)\cdot z}{d\cdot\pi\cdot a}\cdot arctg\left(\dfrac{x}{z}\right)-\dfrac{z}{\pi\cdot a}\cdot arctg\left(\dfrac{x+a}{z}\right)+\right. \\ \left.+\dfrac{z}{\pi\cdot d}\cdot arctg\left(\dfrac{-x+d}{z}\right)\right]-\gamma\cdot\left(H-h\right)\cdot\left[\dfrac{\left(d_1+a_1\right)\cdot z}{d_1\cdot\pi\cdot a_1}\cdot arctg\left(\dfrac{x}{z}\right)-\right. \\ \left.-\dfrac{z}{\pi\cdot a_1}\cdot arctg\left(\dfrac{x+a_1}{z}\right)+\dfrac{z}{\pi\cdot d_1}\cdot arctg\left(\dfrac{-x+d_1}{z}\right)\right]. \\ d=b-a;\quad d_1=b_1-a_1. \end{array}\right\} \quad (12)$$

If the cross section of the soil dam has the shape of an isosceles trapezoid, then $d=a$, $d_1=b_1$, $b=2\cdot a$ and $b_1=2\cdot a_1$. Therefore, in this case, the tangential stresses $\tau_{xz}(x,z)$ are equal

$$\left.\begin{array}{l} \tau_{xz}\left(x,z\right)=\dfrac{\gamma\cdot H}{\pi\cdot a}\cdot z\cdot\left[arctg\left(\dfrac{x}{z}\right)-arctg\left(\dfrac{x+a}{z}\right)+arctg\left(\dfrac{-x+a}{z}\right)\right]- \\ -\dfrac{\gamma\cdot\left(H-h\right)}{\pi\cdot a_1}\cdot z\cdot\left[arctg\left(\dfrac{x}{z}\right)-arctg\left(\dfrac{x+a_1}{z}\right)+arctg\left(\dfrac{-x+a_1}{z}\right)\right]. \\ b=2\cdot a;\quad b_1=2\cdot a_1. \end{array}\right\} \quad (13)$$

The analytical expressions obtained by us for the stresses acting in the foundation of soil dams allow us to estimate the strength of the foundation at any point using the well-known Coulomb-Mohr criterion [9, 14, 15]. We have

$$\left.\dfrac{\sigma_1\left(x,z\right)-\sigma_3\left(x,z\right)}{\sigma_1\left(x,z\right)+\sigma_3\left(x,z\right)-2\cdot P\left(x,z\right)+2\cdot c\cdot ctg\left(\varphi\right)}\le\sin\left(\varphi\right)\right\} \quad (14)$$

$$\left.\begin{array}{c}\text{if the excess pressure in the pore fluid of the base is zero;}\\ \dfrac{\sigma_1(x,z)-\sigma_3(x,z)}{\sigma_1(x,z)+\sigma_3(x,z)-2\cdot P(x,z)+2\cdot c\cdot ctg(\varphi)}\le\sin(\varphi)\\ \text{if the pressure in the pore fluid of the base is equal to } P(x,z).\end{array}\right\}\qquad(14)$$

Here

$$\left.\begin{array}{l}\sigma_1(x,z)=\dfrac{\sigma_x(x,z)+\sigma_z(x,z)}{2}+\dfrac{1}{2}\cdot\sqrt{\left[\sigma_x(x,z)-\sigma_z(x,z)\right]^2+4\cdot\tau_{xz}^2(x,z)};\\ \sigma_3(x,z)=\dfrac{\sigma_x(x,z)+\sigma_z(x,z)}{2}-\dfrac{1}{2}\cdot\sqrt{\left[\sigma_x(x,z)-\sigma_z(x,z)\right]^2+4\cdot\tau_{xz}^2(x,z)}.\end{array}\right\}\qquad(15)$$

where and σ_3 - the main stresses in the foundation; P - excess pressure in the pore fluid; c - specific coupling; φ - angle of internal friction; σ_x, σ_z and τ_{zx} - see the explanation of the formulas (5)-(13).

Determining the vertical movement of the base of the dam

According to formulas [9, 14], in the case of plane deformation, the vertical relative deformation of the base should be determined by the formula

$$\varepsilon_z(x,z)=\frac{1}{E}\cdot\left[(1-\nu)^2\cdot\sigma_z(x,z)-\nu(1+\nu)\cdot\sigma_x(x,z)\right]\qquad(16)$$

where

$$U_z(x,z)=\frac{1}{E}\cdot\left[(1-\nu)^2\cdot\int\sigma_z(x,z)\cdot dz-\nu(1+\nu)\cdot\int\sigma_x(x,z)\cdot dz\right]+F(x)\qquad(17)$$

Here - $\varepsilon_z(x,z)$ vertical relative deformation of the base; $U_z(x,z)$ - the same, displacement; E and ν - elastic technical constants of the base (modulus of elasticity and Poisson's ratio, respectively); $\sigma_z(x,z)$ and $\sigma_x(x,z)$ - vertical and horizontal normal stresses; $F(x)$ - some arbitrary function of the coordinate x.

When calculating subsidence, the method of layer-by-layer summation is currently used [1,2,3-9]. Therefore, we will find the subsidence of the base on the depth interval $z\in(z_1,\ z_2)$. For the convenience of presenting the material, we will put

$$I_{z,1}(x,z)=\frac{(1-\nu)^2}{E}\cdot\int\sigma_z(x,z)\cdot dz;\quad I_{z,2}(x,z)=\frac{\nu(1+\nu)}{E}\cdot\int\sigma_x(x,z)\cdot dz\qquad(18)$$

Then the subsidence $S_i(x)$ of a layer of thickness $h_i=z_{2,i}$-$x_{1,i}$ and $z_{2,i} \geq z_{1,i}$ will be equal to

$$
\left.
\begin{aligned}
&S_i(x)=U_z\left(x,z_{2,i}\right)-U_z\left(x,z_{1,i}\right);\;\; U_z(x,z)=I_{z,1}(x,z)+I_{z,2}(x,z);\\
&I_{z,1}(x,z)=\frac{(1-\nu)^2}{E}\cdot\int\sigma_z(x,z)\cdot dz;\;\; I_{z,2}(x,z)=\frac{\nu(1+\nu)}{E}\cdot\int\sigma_x(x,z)\cdot dz;\\
&\int\sigma_z(x,z)\cdot dz=\frac{x^2\cdot(a+d)}{\pi\cdot a\cdot d}\cdot\ln\left(\frac{x}{z}\right)+\frac{(x+a)}{\pi\cdot a}\cdot arctg\left(\frac{x+a}{z}\right)+\\
&+\frac{(d-x)^2}{2\cdot\pi\cdot d}\cdot\ln\left[1+\frac{(-x+d)^2}{z^2}\right]-\frac{(d-x)^2}{\pi\cdot d}\cdot\ln\left[\frac{-x+d}{z}\right]-\\
&-\frac{x^2\cdot(d+a)}{2\cdot\pi\cdot d\cdot a}\cdot\ln\left(1+\frac{x^2}{z^2}\right)-\frac{x\cdot z\cdot(d+a)}{\pi\cdot d\cdot a}\cdot arctg\left(\frac{x}{z}\right)+\\
&+\frac{(x+a)^2}{2\cdot a\cdot\pi}\cdot\ln\left[1+\frac{(x+a)^2}{z^2}\right]-\frac{(x+a)^2}{a\cdot\pi}\cdot\ln\left[\frac{x+a}{z}\right]+\\
&+\frac{(-x+d)}{\pi\cdot d}\cdot arctg\left(\frac{-x+d}{z}\right);\\
&\int\sigma_x(x,z)\cdot dz=\frac{1}{2}\cdot\frac{(a+d)\cdot\left(x^2+z^2\right)\cdot\ln\left(x^2+z^2\right)}{\pi\cdot a\cdot d}-\\
&-\frac{1}{2}\cdot\frac{\left[z^2+(-x+d)^2\right]\cdot\ln\left[z^2+(-x+d)^2\right]}{\pi\cdot d}-\frac{1}{2}\cdot\frac{\left[z^2+(x+a)^2\right]\cdot\ln\left[z^2+(x+a)^2\right]}{\pi\cdot a}+\\
&+\frac{x^2\cdot(d+a)\cdot\ln(x/z)}{\pi\cdot a\cdot d}+\frac{x+a}{a\cdot\pi}\cdot\arctan\left(\frac{x+a}{z}\right)+\frac{d+a}{2\cdot\pi}-\\
&-\frac{(x+a)^2}{\pi\cdot a}\cdot\ln\left(\frac{x+a}{z}\right)-\frac{(-x+d)^2}{\pi\cdot d}\cdot\ln\left(\frac{-x+d}{z}\right)+
\end{aligned}
\right\}\qquad(19)
$$

$$
\left.
\begin{aligned}
&+\frac{(x+a)^2}{2\cdot\pi\cdot a}\cdot\ln\left[1+\frac{(x+a)^2}{z^2}\right]+\frac{(-x+d)^2}{2\cdot\pi\cdot d}\cdot\ln\left[1+\frac{(-x+d)^2}{z^2}\right]-\\
&-\frac{x\cdot z\cdot(d+a)}{a\cdot\pi\cdot d}\cdot arctg\left(\frac{x}{z}\right)-\frac{x^2\cdot(d+a)}{2\cdot a\cdot\pi\cdot d}\cdot arctg\left(1+\frac{x^2}{z^2}\right)+\\
&+\frac{z\cdot(-x+d)}{\pi\cdot d}\cdot arctg\left(\frac{-x+d}{z}\right);\;\; d=b-a.
\end{aligned}
\right\}\qquad(19)
$$

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If the transverse profile of the dam has the shape of an isosceles trapezoid, then in (19) should be put $d=a$.

Formula (19) makes it possible to use the well-known method of layer summation and the DBN formula to calculate the settlement of the foundations of soil dams due to additional stresses from the weight of the dam, namely

$$S\left(x\right)=\sum_{i=1}^{n} S_i\left(x\right), \tag{20}$$

where $S(x)\sum_{i-1}^{n} S_i(x)$ - settlement of the base of the dam at the point with the coordinate (see formula (19)), and $S_i(x)$ - settlement of the elementary layer of the base with thickness h_i, whose covering is at depth $z_{1,i}$, and the sole on the deep $z_{2,i}$.

If you do not need a very high accuracy of determining the settlement of the dam base, then the settlement due to additional stresses from the weight of the dam can be calculated using the well-known DBN formula

$$\left.\begin{aligned} S\left(x\right)=\beta\cdot\sum_{i=1}^{n}\frac{\sigma_z\left(x,z_{1,i}\right)+\sigma_z\left(x,z_{2,i}\right)}{2\cdot E_i}\cdot h_i; \\ h_i=z_{2,i}-z_{1,i}. \end{aligned}\right\} \tag{21}$$

Here $S(x)$, $z_{1,i,}$ $z_{2,i}$ - see explanation of the formula (20), σ_z - additional stress in the base, which should be determined by formulas (8) and (9), β=0,8, and E_i - the modulus of the general deformation of i - th soil layer at the depth interval. Finally, in the third part of this study, we present one of the options for using the theoretical results obtained by us regarding the determination of the stressed-strained state of an soil dam constructed of heterogeneous materials. An illustration of our proposed approach for this purpose is presented in fig. 3.

It follows from the figure that if it is necessary to calculate the stressed-strained state of the base of an soil dam in which the dam body has a specific weight γ_1, and the core - γ_1, then you should proceed as follows:

1. To perform calculations, you should use the calculation scheme in fig. 2. Herewith:

1.1. If you need to determine vertical stresses σ_z, you should use formulas (8) and (9).

1.2. If you need to determine horizontal stresses σ_x, you should use formulas (10) and (11).

1.3. If you need to determine tangential stresses τ_{zx}, you should use formulas (12) and (13).

1.4. If it is necessary to determine the settlement (i.e.vertical movements) of the base of the dam, formulas (17), (18), and (19) should be used.

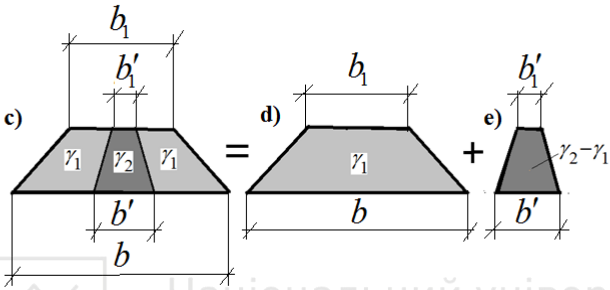

Fig. 3. The scheme of using the theoretical results obtained by us for the calculation of base of soil dams from materials with different specific gravity

Notes:

1. γ_1 - specific gravity of the dam body; γ_1 - specific gravity of the dam core.

2. The heights of the dam elements with different specific gravity are the same.

2. To determine each of the stress and displacement components listed in p.1 of this algorithm in relation to the one presented in fig. 3-c of the scheme, the following actions should be performed:

2.1. First, you should calculate the values of stresses and displacements for the one shown in fig. 3-*d* of the calculation scheme. At the same time, the specific weight of the dam material should be taken as equal γ_1.

2.2. Next, you should calculate the values of stresses and displacements for the shown in fig. 3-*e* calculation scheme. At the same time, the specific weight of the dam material should be taken as equal γ_2-γ_1.

2.3. The results obtained in this way should be added up.

Conclusions

In general, this monograph presents the following results:

1. Within the framework of the model of base in the form of a linear elastic isotropic habitat and planar deformation calculation scheme obtained analytical dependences of stresses and deformations of the half-plane, to the upper limit of which a trapezoidal load is applied in the form of an equilateral and an equilateral trapezoid.

These data are necessary for the calculation for the first and second groups of limit states of base of dams made of soil materials, embankments of railways and highways, and other structures located on foundations composed of weak soils.

2. Algorithms for determining the subsidence of the sole of soil dams due to additional stresses in the base due to the weight of the dam are proposed.

3. An algorithm for determining the stress-strain state of base of soil dams,made of materials with different specific gravity has been developed.

In conclusion, it should be noted that the research materials presented in this monograph should be used in the design of transport, energy and agricultural facilities.

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ECONOMIC JUSTIFICATION OF RATIONAL NATURAL USE AS AN EXAMPLE OF NATIONAL ENERGY DEVELOPMENT

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Abstract

The study presents the economic justification of rational nature use on the example of the development of the national energy industry of Ukraine. To date, it has not been possible to fundamentally rebuild the economic complex of Ukraine on ecologically favorable intensive pro-European principles of nature management activities.

The industries dangerous for the environment of Ukraine include the fuel and energy, metallurgical, heavy engineering, chemical and petrochemical industries; agro-industrial complex; communal economy; transport (especially automobile). The gradual mastering of the experience of nature use and the acquisition of knowledge by mankind about the use of natural resources had both positive and negative consequences. The study presented the level of emissions of the main pollutants into the atmospheric air in Ukraine, the level of discharge of polluted return water into natural surface water bodies by regions of Ukraine, as well as the most polluted settlements in Ukraine by the content of industrial toxicants in the soil. Taking into account the technological level of PEK, the total need for innovative financing (according to experts' estimates) is from UAH 8 to 12 billion annually. Economic entities will not be able to obtain such financial resources by their own efforts without targeted foreign investment. Therefore, the problem of creating an attractive investment climate in the PEK of Ukraine for the activation of innovative processes has acquired special importance.

Introduction

During the years of independence, it has not yet been possible to fundamentally rebuild the economic complex of Ukraine on ecologically favorable intensive pro-European principles of nature management activities.

Among European countries, Ukraine has the highest integrated indicator of negative man-made loads on the natural environment in almost its entire territory. The international status of our state is officially recognized as an "ecological disaster zone" taking into account more than 10% of the territory of Ukraine, its ecological state, levels of environmental pollution and the state of use of the main natural resources. This status was obtained after the accident at the Chernobyl nuclear power plant, because along with pollution and ecological cataclysms, radioactive contamination of part of the territory was also added. As a result, the cumulative negative impact on people and the natural environment of various chemical pollution and radiation, degradation processes and deterioration of the quality of the environment has significantly increased.

The industries most dangerous for Ukraine's environment include industry (fuel and energy, metallurgy, heavy engineering, chemistry and petrochemicals); agro-industrial complex; communal economy; transport (especially automobile). The study presented the level of emissions of the main pollutants into the atmospheric air in Ukraine, the level of discharge of polluted return water into natural surface water bodies by regions of Ukraine, as well as the most polluted settlements of Ukraine by the content of industrial toxicants (in multiples of MAC) in soils.

Therefore, the gradual mastering of the experience of nature use and the acquisition of knowledge by mankind regarding the use of natural resources, and, in particular, their energy component, had both positive and negative consequences. In particular, with the development of human society, the speed of scientific and technological progress is increasing. There is a violation of the state of equilibrium in the "nature-man" system, there is a threat to the very existence of humanity; all this requires rational and ecologically safe management and highly efficient balanced use of natural resources (fuel and energy in particular), which will create favorable conditions for human health, preservation and reproduction of the natural environment and the natural resource potential of social production [1-5].

1. Analysis of the national energy industry as a systemic nature user

Energy is the main strategic prerequisite for the development of the economy, the basis for ensuring all types of life activities of society. Therefore, the definition and implementation of directions for its development are priority tasks in ensuring national security, political and energy independence, and sustainable development. The fuel and energy complex of Ukraine includes exploration and production, processing and production, storage and transportation, transmission and distribution, trade and sales (sale) of energy products - fuel, electricity and thermal energy. Formed at one time as a component of the fuel and energy complex of the USSR, it does not fully meet the conditions for the functioning of the energy industry on the basis of sustainable development. Thus, the general structure of the fuel and energy complex of Ukraine consists of several main production industries, such as: oil and gas production and oil refining industry, coal mining, electric power industry (Fig. 1).

The oil industry of Ukraine is one of the oldest in the world. The total resources of oil and gas condensate amount to 1041 million tons. Since the beginning of industrial exploitation, 375 million tons have been mined, including about 85 million tons in the last 20 years. In three (Eastern, Western and Southern) oil and gas-bearing regions of Ukraine, 41% of the resources have been explored. The eastern region contains about 60% of the country's oil reserves. 205 hydrocarbon deposits have been discovered on its territory, 180 of them have been entered into the state register. The total production reaches 75% of the total in the industry [6-9].

The Western oil and gas-bearing region is located mainly in the Carpathian region, and provides production of up to 20% of oil and gas condensate from the total volume of the industry. It is gradually losing its production value due to the exhaustion of explored reserves. The southern oil and gas-bearing region covers the Western and Northern Black Seas, the Azov Sea, and the Ukrainian zones of the Black and Azov Seas. It is the most promising in Ukraine, it provides crude oil and, especially, gas condensate with high quality indicators, but the development of its deposits (especially marine ones) requires significant capital investments.

The main business entity of the industry is PJSC "Ukrnafta" - a de facto monopolist on the relevant market. 50% + 1 share of this monopolist belongs to Naftogaz of Ukraine. PJSC "Ukrnafta" accounts for up to 85% of annual oil production in Ukraine (and together with gas condensate - up to 70%). There are 296 deposits on the state balance sheet, 236 deposits are in industrial exploitation.

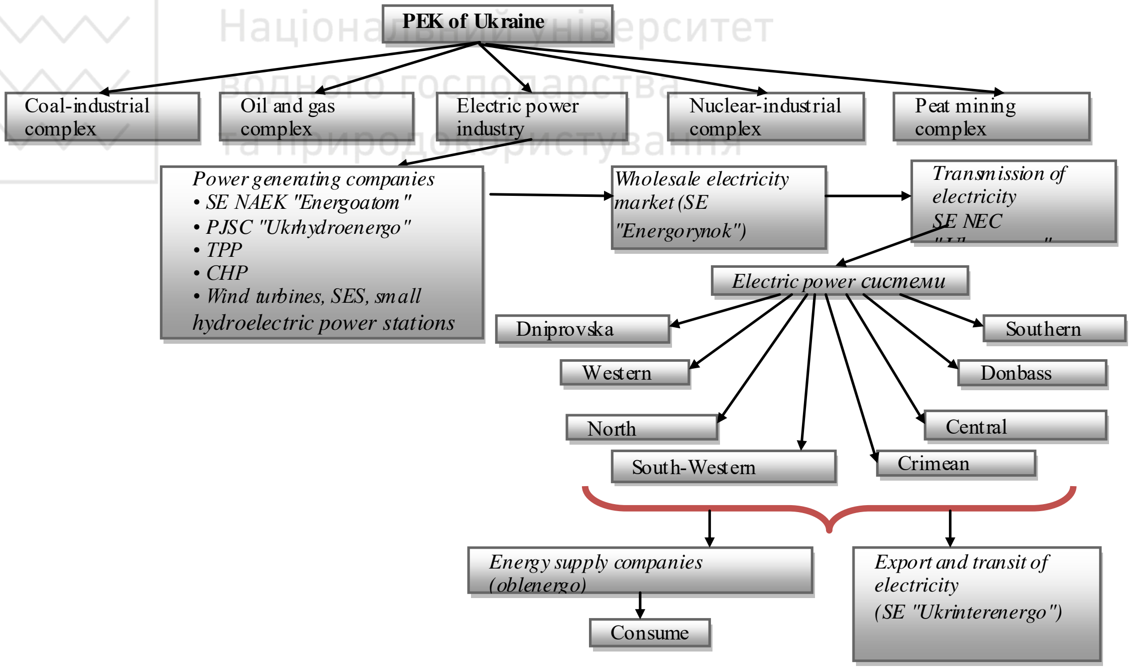

Fig. 1. Fuel and energycomplex of Ukraine

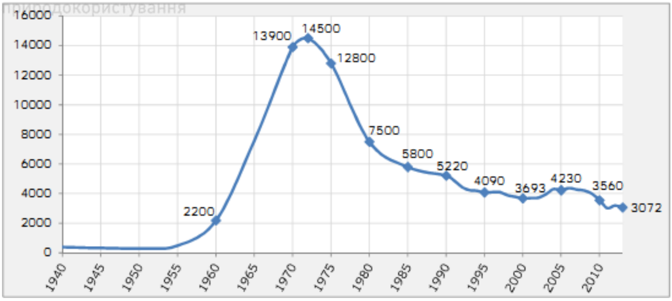

Fig. 2. Extraction of oil and gas condensate in Ukraine, thousand tons

The reduction in production is associated with a number of systemic problems, the main ones of which are shown in Fig. 3.

Problems of the development of the oil industry of Ukraine

- depletion of reserves of most deposits, primarily basic, as a result of long-term exploitation (from 30-40 to 100 or more years) and write-off of reserves, the presence of which was not confirmed during industrial development
- dependence on imports and reduction of own production; a significant reduction in the scope of prospecting and exploration work and a reduction in the scope and efficiency of operational drilling
- constant deterioration of the structure of reserves (for many years, mainly those of them, which were easier to access, were developed)
- low reliability of the raw material base
- low level of material base and lack of specialists for geological exploration
- lack of widespread use of innovative technologies and technical means of exploration and development of deposits
- irrational state policy; economically unjustified subsoil use fee rates (rent payments)
- worn-out technical base, morally outdated production, unfavorable price situation on the market, low depth of oil processing, high cost of production, unsatisfactory product quality

Fig. 3. Problems of development of the oil industry of Ukraine

The industry has recently significantly reduced the volumes of oil and condensate production - from 4,5 million tons (2006) to 3,5 million tons (2013) (Fig. 2).

Thus, the reduction in the volume of prospecting works (from 425,000 m in 1991 to 152,000 m in 2010) is significant. In 20 years, only one large oil field was discovered (Subotynskoe, reserves of 65 million tons). The volumes of exploration work carried out in 2006-2011 at the expense of all sources of financing are 5 times smaller than necessary for sustainable reproduction of the raw material base; that is, there is a process of curtailment of industrial production in the near future. The use of innovative oil production technologies is extremely low. For example, investment in fixed capital per 1 ton of oil produced in Ukraine is more than half of the average European level.

As for the development of the gas industry, it operates on a relatively small resource base - proven reserves of natural gas in Ukraine amount to 1193 billion cubic meters, forecast resources - 3491 billion cubic meters. The largest reserves (43 percent of total forecast reserves) are in Eastern Ukraine. The shelf of the Azov and Black seas is also promising - up to 46% of the forecast reserves. The forecast reserves of unconventional gas are potentially promising:

- 1,2 trillion cubic meters of shale gas;
- 8,5 trillion cubic meters of gas from dense collectors;
- more than 12 trillion cubic meters of coal bed methane.

Own gas production in 2014 amounted to 19.8 billion cubic meters (increased by 2,4% compared to 2013), but the overall level of gas production is decreasing (Fig. 4).

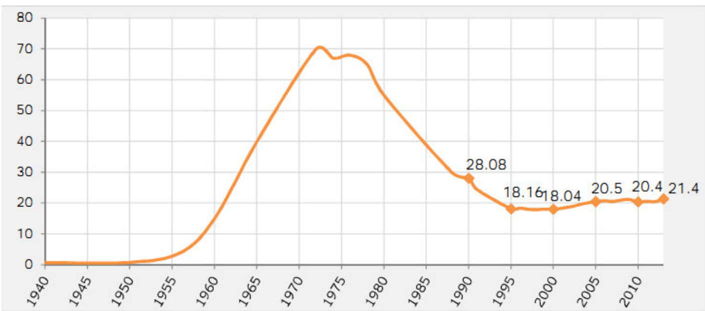

Fig. 4. Historical trend of natural gas extraction in Ukraine, billion m³

The problems of the functioning of the gas production industry are similar to the problems of oil production, but they are specific, taking into account the transit capabilities of the gas transportation system of Ukraine (Fig. 5).

Problems of the development of the gas industry of Ukraine

- the monopoly position of Naftogaz of Ukraine, which leads to the degradation of the gas industry and the laundering of huge state financial resources
- the existence of an extremely unfavorable gas purchase and sale agreement between Gazprom OJSC and Naftogaz of Ukraine for the period 2009-2019, including the provisions of this agreement regarding the determination of gas delivery and acceptance points (on the border with the EU, not on Ukrainian Russian border)
- the need to carry out a large-scale modernization of the GTS in the absence of funds from NJSC "Naftogaz of Ukraine"
- the current lack of a liberalized and organized natural gas market in Ukraine in accordance with the requirements of the 2nd and 3rd EU energy packages
- lack of real separation of the natural gas supply system operator – PJSC "Ukrtransgaz" from JSC "Naftogaz of Ukraine"
- lack of membership of the natural gas supply system operator – Ukrtransgaz PJSC in ENTSO-G, in accordance with the requirements of the 3rd EU energy package
- unprofitable activity of NJSC "Naftogaz of Ukraine" in the supply of natural gas for the needs of thermal energy and TKE, as well as the population due to the use of fixed tariffs that do not cover the cost of gas
- unsatisfactory pace of reorganization of oil and gas enterprises in accordance with the requirements of the EU Energy Directives, especially regarding the separation of gas distribution and supply activities
- unsatisfactory conditions for attracting non-state investors for the development of traditional and unconventional gas production projects; significant reduction in the scope of search and reconnaissance work
- the presence of a privileged pricing policy for specific consumer groups and the absence of uniform pricing principles for all consumer groups; economically unjustified subsoil use fee rates (rent payments)

Fig. 5. Problems of the development of the gas industry of Ukraine

Thus, the design capacity of the gas transportation system of Ukraine is 178,5 billion cubic meters per year, including 142,1 billion cubic meters in the direction of EU countries and Turkey. In 2013, the transit of natural gas for the CIS countries and Europe amounted to 86,1 billion cubic meters. Due to the political motives of JSC Gazprom, there is an annual reduction in transit volumes. In addition, Ukraine's gas transportation system is facing the threat of partial conservation not only for political reasons, but also for technical reasons: it has been in need of significant investments for renewal and reconstruction for a long time.

Oil and gas industries have a lot in common in the nature of their impact on the environment. In particular, the main source of pollution in the oil and gas industry is the so-called reservoir water (which comes to the surface during drilling and extraction). According to the chemical composition, reservoir waters are highly mineralized brines with a high content of chloride salts, carbonates, and alkali metals. It is formation waters that make up to 90% of waste water - the main factor of environmental pollution during the exploration and operation of oil and gas wells. Wastewater also contains oil, sulfur, iron oxides, and hydrogen sulfide. This causes oil pollution of reservoirs and aquifers, a critical change in the physical and chemical properties of soils. Main oil and gas pipelines are also a potential source of pollution with a significant negative impact on the environment in case of accidental damage to the network.

The oil refining industry of Ukraine is represented by six oil refineries with a total design annual processing capacity (as of 2014) of 52 million tons of crude oil. However, the actual actual capacity is no more than 15 million tons. Only one Kremenchug oil refinery is actually operating. In addition, 7 more gas processing plants produce petroleum products from gas condensate. In 2014, a total of only 2,6 million tons of raw materials were processed in Ukraine, which made it possible to supply the domestic market with its own petroleum products by only 15%.

The main problems of the oil refining industry of Ukraine include:

- technological backwardness;
- lack of investment;
- failed privatization of enterprises;
- dependence on the import of raw materials (during the years of independence, oil production in Ukraine decreased by 1,8 times);
- lack of effective sectoral state policy.

The oil refining industry (despite limited production volumes) remains a significant polluter of the environment. In 2012 (together with the coke industry), the total emission of pollutants into the atmosphere amounted to 797 thousand tons (about 20 kg per one resident of Ukraine) [10-14].

Analyzing the coal mining industry, it is worth noting that in terms of geological reserves of fossil coal, Ukraine ranks first in Europe and eighth in the world. Explored reserves amount to about 56 billion tons, forecast reserves - about 170 billion tons of coal of all grades - from brown to anthracite and coking coal. In recent years, production has remained at the level of 72-83 million tons of coal per year (Fig. 6).

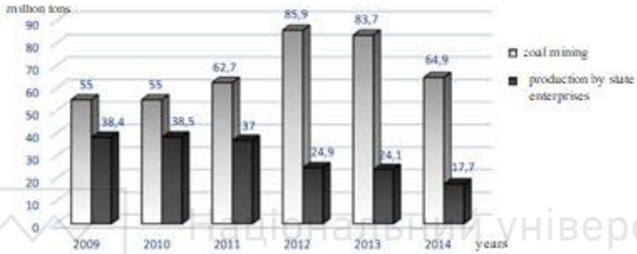

Fig. 6. Volumes of coal production in Ukraine for 2009-2014

The coal mining industry is the basis for the fuel and energy complex of Ukraine. At the same time, it is burdened with a whole set of problems (Fig. 7).

The coal mining industry has a complex man-made impact on the environment, namely, changes in natural hydrological regimes; significant areas of land are taken out of the standard ecological regime for landfills and landfills; stationary powerful sources of harmful emissions into the atmosphere and hydrosphere are created.

Thus, from Table 1, we can see that during the years 2010-2015, the volumes of emissions into the atmosphere of pollutants (from 743,3 thousand tons in 2011 to 424,7 thousand tons in 2015) and carbon dioxide (from 2340, 1 thousand tons in 2011 to 384,0 thousand tons in 2015). However, in general, as of 2015, the coal mining industry accounted for about 15% of pollutant emissions from the total emissions by all industries.

Problems of the development of the coal industry of Ukraine

- destruction of the infrastructure of the industry as a result of military events in the East of Ukraine
- catastrophic aging of fixed assets (40 percent of mines have been operated for more than 70 years, not a single new mine was built during the years of independence)
- complication of mining conditions (deep occurrence of formations, high explosiveness, transition to work on narrow formations)
- investment deficit
- lack of real privatization
- low rates of reconstruction and technical re-equipment of mines, the presence of outdated technologies and the reduction of scientific potential
- overloading of economic entities with social burden

Fig. 7. Problems of the development of the coal industry of Ukraine

The peat-mining industry in Ukraine is represented by 9 peat-mining enterprises (in the Volyn, Zhytomyr, Kyiv, Khmelnytskyi, Rivne, Sumy, and Chernihiv regions). They are united in the state concern "Ukrtorf". During 2014, they produced 194,6 thousand tons of peat briquettes. The total explored peat deposits (with an area of more than 10 hectares) amount to 1,8 million tons.

Table 1

Emissions of pollutants and carbon dioxide by coal mining enterprises of Ukraine during 2010-2015

	Volumes of emissions			
	pollutants		carbon dioxide	
	thousand tons	in % of the total emissions of industries	thousand tons	in % of the total emissions of industries
2011	743,3	17,0	2340,1	1,16
2012	772,9	17,8	2884,4	1,6
2013	760,1	17,7	1057,6	0,5
2014	424,7	13,3	529,2	0,3
2015	424,7	14,9	384,0	0,3

In the conditions of significant dependence of the economy of Ukraine on imported fuel and energy resources (natural gas, oil) and the constant increase in their prices, solving the issue of stimulating the development of the peat mining industry as one that provides alternative energy carriers becomes an urgent state necessity. And although peat, geologically the youngest link in the chain of caustobiolites "peat - lignite - hard coal - anthracite", has the lowest level of carbonization and, accordingly, the lowest value of the heat of combustion, the surface location of peat deposits and relatively small costs for the organization and management of mining works make this useful mineral a potentially effective means of energy saving.

Ukraine is the southernmost country in Europe, where peat resources are of industrial importance, which makes peat a real reserve for improving Ukraine's fuel and energy balance. Three Polish regions have the largest peat resources: Volyn, Rivne, and Chernihiv. 1,051 deposits (36% of all deposits in the country) have been discovered and explored on their territory, and geological reserves of peat amount to 1,09 billion tons (50% of Ukraine's reserves).

The amount of peat in the Polish districts of Volyn, Rivne, and Zhytomyr regions reaches 15%. In the western and eastern Polissia, medium-sized deposits (200-1000 hectares) predominate, and in the central Polissia (Kyiv and Zhytomyr regions) small ones - up to 100 hectares.

At this stage of the development of Ukraine's economy, the question of using peat for the development and formation of "small energy" systems and means is relevant, with the aim of obtaining high-quality liquid and gaseous fuel for use in the housing and communal services system, as well as in other economic sectors.

Currently, scientists are working on the technology and equipment of the technological line of biophysical processing of peat, wood and plant waste into liquid and gaseous fuel by the method of "fast pyrolysis" with the output of liquid fuel and gas in volumes of up to 40% of the mass of dry organic matter (sawdust, husk, peat). Energy costs for the implementation of the technology do not exceed 20% of the energy content of the obtained liquid and gaseous fuel. The heat of combustion of the obtained liquid fuel is 42 kJ/kg, corresponding to diesel fuel.

The use of RES energy will save traditional scarce energy resources and improve the ecology of production. However, the state's current lack of incentive measures aimed at supporting the independent development of peat mining enterprises does not allow it to ensure the proper use of energy potential, which in turn puts obstacles in the way of reducing Ukraine's energy dependence on imported energy carriers (natural gas, oil).

The electric power industry is the last link in the technological chain (from the extraction of energy raw materials to the direct production of energy). According to the sources of electricity generation, it has a branched structure, it includes nuclear power plants (NPP); thermal power plants (TES) and power plants (CHP); hydroelectric power plants (HPP); wind power plants; solar power plants; bioenergy installations.

The United Energy System of Ukraine (UES) has a total installed power plant capacity of 54,5 GW and is one of the largest in Europe. Thus, electricity production in the unified energy system of Ukraine in 2014 amounted to 182,815.4 million kWh. and compared to 2013, it decreased by 5,8%; in 2013, production decreased by 2,3% compared to the same period in 2012 and amounted to 194,377,3 million kWh.

The structure of electricity production in 2014 is shown in Fig. 8.

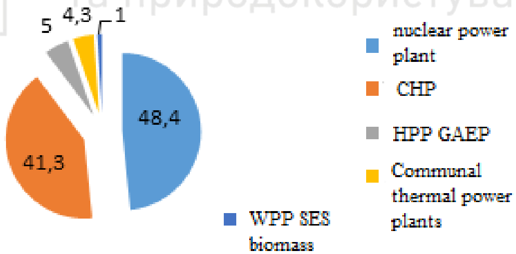

Fig. 8. Structure of electricity production in 2014

As we can see from Fig. 8, thermal power plants and thermal power plants, as well as nuclear power plants, which together provide about 90% of annual electricity production, are dominant in electricity generation. It is worth noting that the so-called thermal power generation (TPP and CHP) is in a pre-crisis state due to the lack of investment and systematic work on the modernization and renovation of power-generating equipment. All TPP and CHP power units were put into operation 40-50 years ago and are characterized by low reliability and efficiency and a high level of emissions of pollutants. Out of 102 power units, 93 (90%) have already exceeded the limits of physical wear, marginal and estimated work resources. Over the past 20 years, no new thermal power generation capacities have been introduced.

The problems in the operation of heat and power generation in Ukraine are typical, as well as for other branches of the state's PEC (presented above). However, since 2014, they have been supplemented by another significant shortage - coal shortage (due to the military conflict in Eastern Ukraine) (Fig. 9).

15 power units with a total installed capacity of 13.9 MW operate at 4 nuclear power plants of Ukraine. On average, they served half of the service life provided by the projects. The existing state program for extending the operating life of each power unit will allow (provided it is timely and fully funded) to preserve the nuclear power industry of Ukraine as a basic branch of the national energy sector for the next 10-15 years. The issue of the completion of 2 power units at the Khmelnytskyi NPP has been postponed for a later period for political reasons.

An additional problem for nuclear power generation in Ukraine is the need to develop its own raw material base and diversify sources of nuclear fuel supply. In terms of discovered uranium reserves, Ukraine ranks first in Europe and sixth in the world. At the same time, own production of uranium raw materials meets the needs of the NPP by only 30%. The construction of the plant for the production of nuclear fuel is suspended. The domestic nuclear power industry mainly uses Russian-made heat-emitting elements to load reactors. The processing of NPP nuclear waste has not yet been fundamentally resolved.

The hydroelectric power industry of Ukraine, despite its relatively small share in the total volume of electricity generation (about 5-6%), plays an important role in ensuring the stability of the combined power system, as it provides it with highly maneuverable capacities in regulating daily load schedules. PJSC "Ukrhydroenergo" includes the combined power plants of the Dnipro and Dniester Cascades, which on average provide annual electricity production of about 11 billion kWh.

Problems of development електроенерге-

- a high level of physical and moral wear and tear of the main and auxiliary equipment of power plants, objects of trunk and distribution networks
- destruction of the energy infrastructure in the East of Ukraine
- the existence of cross-subsidization
- relatively low level of regulated prices for end consumers
- lack of membership of the domestic electricity transmission system operator in ENTSO-E, in accordance with the requirements of the 3rd EU energy package
- shortage of regulatory capacities in the UES of Ukraine
- unpreparedness of electric grids for RES development
- growing amounts of consumer debt for electric energy, debt in ORE
- the presence of a privileged pricing policy for specific consumer groups and the absence of uniform pricing principles for all consumer groups
- lack of economically justified tariffs for electricity transmission in networks and deregulation of electricity prices
- the need for a clearer definition of socially vulnerable electricity consumers in accordance with the recommendations of the Energy Community
- lack of mechanisms for implementing measures to limit emissions from large combustion plants in the power industry
- insufficient financial provision of measures to improve the safety of nuclear power plants and the protection of the energy infrastructure as a whole; lack of financial support for the construction of new NPP power units; lack of capacity for own production of nuclear fuel

Fig. 9. Problems of the development of the electric power industry of Ukraine

Ukraine has a sufficient potential of renewable energy sources, which allrows to significantly reduce the volume of use of traditional natural resources (experts of the Institute of Renewable Energy of the National Academy of Sciences of Ukraine predict that by 2030, 30% of energy carriers from traditional sources will be replaced by energy carriers from renewable sources).

The "green" tariff operating in Ukraine ensures the attraction of non-state investments and the intensive development of renewable energy. In 2013, the annual volume of electricity produced by renewable electricity generation exceeded 1 billion kWh. As of July 1, 2014, the installed capacity of wind power plants was 497 MW, solar power plants - 819 MW, small hydropower plants - 77 MW, biomass and biogas electricity production facilities - 26 MW.

Electricity is transported by trunk and distribution networks. The length of trunk networks (voltage from 35 kV to 800 kV) is 23.2 thousand km, the length of distribution networks (voltage from 0.4 to 150 kV) is about 1 million km. The power supply system includes 136 main transformer substations and about 200,000 distribution transformer substations. Power grids have the same problem as power generation - they need urgent renewal and reconstruction. Thus, as of January 1,2013, 42,2% of overhead power transmission lines with a voltage of 220-330 kV in the main power grid had been in operation for more than 40 years, 64.4% of transformer substations had exhausted their estimated technical resource. In the distribution network, up to 40% of lines and transformer substations need to be replaced or overhauled.

In order to fully understand the development of the branches of the fuel and energy complex of Ukraine, we will conduct an analysis of property relations, basic organizational, legal and economic relations and the position of state management bodies regarding the state of affairs in this sector of the national economy.

During the years of independence, PEK of Ukraine went through three stages of privatization. All of them had one common official declared goal - to attract investments for the modernization and revival of the industry. The first stage - 1997-1998 - consisted in the sale by the government of 20-45 percent stakes in 9 of the 27 existing regional energy companies. It was declared that the new owners take on significant investment obligations and have the right to take over state packages of shares of other regional energy companies (so-called external management). The actual result of the first stage of privatization was the practice of mass withdrawal of funds received from electricity consumers to offshore accounts, instead of to the single account of the energy market. The new owners and the so-called management companies of oblenergo grossly violated the contractual financial relationships between the PEK entities, and put into use barter and promissory note semi-fraudulent settlement schemes. In some months, in Ukraine as a whole, the payment of the energy market for the electricity received by oblenergo amounted to 5-7%. The lack of payments for the generated electricity has put the electricity generating enterprises of PEC on the verge of shutdown, created a threat to the nuclear safety of Ukraine's nuclear power plants. In 1999-2000, the government had to make significant efforts to overcome the catastrophic consequences of the first stage of privatization. A ban on promissory notes and barter schemes of payments for the received electricity was introduced, and the discipline of mutual settlements among energy market participants was increased.

The second stage of privatization began in 2001 and consisted in the sale of shares of another 6 regional energy companies. Unlike the first stage, the sale took place transparently, with the involvement of a strategic investor - the American company AES (acquired Kyivoblenergo and Rivneoblenergo). A categorical requirement was set for the new owners - 100 percent payment for the current (monthly purchased in the energy market) electricity and repayment of the previously accepted electricity debt in accordance with the concluded additional contract. Later, this requirement was extended to the rest of regional energy companies (both privatized at the first stage, and state-owned with external management and simply state-owned). In general, during the next decade, schemes of coexistence of power generation enterprises (state ownership) and almost half (15 out of 27) of privatized power supply companies (oblenergo) were worked out in the energy industry. Practice has shown that there were no significant and the state regulator (the National Energy Regulatory Commission), used the same methodology, which was based on taking into account the amount of useful electricity supply for the corresponding network of subscribers and setting it in electricity tariffs the so-called investment component - a targeted surcharge, which was not paid by the owner of the energy company, but directly by electricity consumers. Additional investment from the owners of energy companies was welcomed, but (despite the provision in the purchase and sale contracts of shares during privatization) was practically differences in investment levels between state-owned and privatized companies. That is, the main declared goal of privatization (attraction of significant investments) was not achieved. Both state-owned and privatized companies, when developing and approving their annual investment programs at the industry ministry not carried out due to the lack of appropriate control over the implementation of privatization contracts by the State Property Fund of Ukraine and the Cabinet of Ministers.

The third stage of privatization - 2011 - 2013 - was carried out non-transparently, without real competition, with a preliminary limitation of the range of possible participants. For this, a requirement was applied - only the participant who already owns shares of energy enterprises is admitted to the tender for the purchase of shares of state-owned companies. The result was that the owners of energy companies became the same financial groups as at the first stage of privatization. It is impossible to call their activities regarding the modernization of the purchased PEK enterprises positive. There was an excessive concentration of shares of energy companies in the hands of a limited circle of inefficient owners. None of them is a strategic investor, does not have the appropriate financial potential (perhaps, except for R. Akhmetov's DTEK group). All of them, in the conditions of the permanent political struggle going on in Ukraine, are constantly in the zone of changing political influences and, even if desired, cannot form a long-term investment policy due to the threat of property redistribution.

As a result, the capitalization of PEK energy distribution enterprises in 2013 fell catastrophically against the level of 2007 - by 80%. The situation is not better in the electricity generating industry of PEK. If in 2007 their total market value was 6,4 billion US dollars, then in 2009 it was only 1,6 billion US dollars. This is a consequence not only of inflation and the fall of the hryvnia exchange rate, but also of a real lack of systematic and significant investment in PE, regardless of the forms of ownership of economic entities.

The structure of ownership and production capacity is shown below in Table 2.

A considerable list of PEK objects remains in state ownership:

- 7 energy supply companies ("Kharkivoblenergo" - 65% of shares; "Khmelnytskoblenergo" - 70,01% of shares; "Zaporizhjiaoblenergo" - 60,25% of shares;

- "Mykolaivoblenergo" - 70% of shares; "Cherkasioblenergo" - 46% of shares; " Ternopiloblenergo" - 51% of shares; "Luhansko-blenergo" - 60,06% of shares);

Table 2

Structure of ownership and production capacity of PEK of Ukraine

Financial and industrial group	Name of the energy supply company	Name of the power generating company (thermal power plant, thermal power plant, hydroelectric power plant, gas power plant)
DTEK	1. "DTEK Dniprooblenergo." 2. "DTEK Donetskoblenergo" 3. "Kyivenergo" 4. "DTEK Krimenergo" 5. "DTEK Service-invest" 6. "DTEK PEM-energy coal"	1. "DTEK Dniproenergo" 2. "DTEK Zahidenergo" 3. "DTEK Eastern Energy" 4. TPP "Kyivenergo" 5. Myronivska TPP 6. "Kyiv CHP - 5" 7. "Kyiv CHP - 6"
VS Energy International Ukraine	1. "EC Zhytomyroblenergo" 2. "Kyivoblenergo" 3. "Kirovogradoblenergo" 4. "EK Odesaoblenergo" 5. "EK Sevastopolenergo" 6. "EK Chernivtsioblenergo" 7. EC Khersonoblenergo" 8. "Rivneoblenergo"	
Svarog Asset Management	1. "Vinnytsia Oblenergo" 2. "Luhansk Energy Association" 3. "Poltavaoblenergo" 4. "Sumioblenergo" 5. "Chernihivoblenergo"	1. "Kremenchutsk CHP" 2. "Crimea CHP"
"Energy Ukraine", "Ukristgaz"	1. "Volynoblenergo" 2. Zakarpattiaoblenergo	1. "Kharkiv CHP - 5"
Energoinvest Holding		1. "Donbasenergo" (60.7% of shares)

- packages of 25% + 1 share of 7 energy supply companies ("Vinny-tsiaoblenergo", "DTEK Dniprooblenergo", DTEK Donetskoblenergo",

"Zakarpattiaoblenergo", "Kyivenergo", "DTEK Krimenergo", "EK Chernivtsi-oblenergo");
- "Regional Electric Networks" enterprise;
- TPP "Donbasenergo" (25% + 1 share);
- TPP "Centroenergo" (78.29% of shares), "Zakhidenergo" (25%+1 share); "DTEK Dniproenergo" (25%+1 share); Dniester HPP (84.79% of shares);
- Dniprodzerzhynska, Kryvorizka, Severodonetsk, Zuyevska, Ukrinterenergo Kaluska, Lysychanska, Kharkivska Eskhar, Odessa, Mykolaivska, Khersonska thermal power plants;
- NPP and HPP of the Dnipro Cascade;
- 50%+1 share of PJSC "Ukrnafta" (49% of shares - sold in previous periods under contractual schemes in the interests of the "Privat" group);
- SE NEC "Ukrenergo";
- SE "Ukrgazvydobuvannya";
- 35 coal mines.

The participation of the state in companies of the oil and gas industry of Ukraine in 2013 is given in Appendix B.

Privatization of NPPs and HPPs of the Dnipro Cascade is prohibited by law. SE NEK "Ukrenergo" as the basic national operator of electricity grids needs significant reform and bringing it into line with the 3rd EU energy package. But even without them, the above list of objects likely to be included in the fourth stage of privatization is more than significant. The main thing is which economic strategy will be the basis: selling to anyone under any conditions just to temporarily replenish the state budget or preparing for the sale of PEK objects and selling them to real investors with a real possibility of reprivatization in case of violations of the conditions of the long-term post-privatization period.

The problems of the technical condition of PEK and the shortcomings of its privatization are largely due to the imperfection of the existing system of state management of the industry. During the years of independence, it underwent a number of reorganizations, the declared goal of which was the transition from sectoral to functional management and approximation to EU standards. As of 2015, its key entities are:

- The Cabinet of Ministers of Ukraine (CMU) is the central body of the executive power of Ukraine;
- The Ministry of Energy and Coal Industry of Ukraine (Ministry of Energy and Coal Industry of Ukraine) is the main body in the system of central executive bodies in the formation and implementation of state policy in the electric power, nuclear industry, coal industry, oil and gas and peat mining complexes;
- The National Commission for State Regulation in the Energy and Utilities Sector (NKREKP) is a state regulatory body in the energy and utility sector, subordinate to the President of Ukraine, accountable to the VRU;
- The State Agency for Energy Efficiency and Energy Saving of Ukraine (Derzhenergoefficitnosti Ukraine) is the central body of the executive power to ensure the implementation of state policy in the areas of effective use of fuel and energy resources, energy saving, renewable energy sources and alternative fuels. The agency's activities are directed and coordinated by the CMU through the Minister of Economic Development and Trade of Ukraine.

These four subjects of state management of the PEC determine prospective and current industry policy, form energy balances, implement tariff policy, etc.

The indirect subjects of state management of the PEK include: the Ministry of Ecology and Natural Resources of Ukraine (Ministry of Natural Resources of Ukraine); Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine (Ministry of Regional Development of Ukraine); Ministry of Economic Development and Trade of Ukraine. The mentioned three ministries indirectly influence the activity of the PEK, applying regulatory means of influence within the limits of their powers.

Vertically integrated natural monopolies with specialization in individual sectors of the energy sector, state-owned economic entities subordinated to and belonging to the sphere of management of the Ministry of Energy and Coal of Ukraine are as follows: DK NEC "Ukrenergo"; JSC "Ukrhydroenergo"; SE NAEK "Energoatom"; SE "Coal of Ukraine"; DK "Nuclear fuel"; JSC "Naftogaz of Ukraine"; DK "Ukrtorf".

The key subjects of management are forced to act in the conditions of the parliamentary-presidential political system in Ukraine, periodically falling under various political influences that do not allow conducting a scientifically and economically sound, purposeful, long-term sectoral policy. Constant (after two or three years) changes of governments, virtually destroyed personnel policy, ambiguous reform of the civil service caused a significant decrease in the level of state branch management in the last 10 years. The same applies to the intermediate subjects of state administration of the PEC.

In such conditions, both vertically integrated natural monopolies and other PEK business entities, on the one hand, are deprived of qualified assistance and coordination, on the other hand, they use the incompetence of industry management and lack of control to allow abuses and violations in financial and economic activity.

In general, the reorganization and reform of the PEK in 2012-2015, despite the relevant declaration by state authorities, have not yet brought the industry closer to the EU requirements, but only partially strengthened the functional capabilities of the state management bodies of the PEK. This is confirmed by the problems in the activity of PEK as a system user of nature, which are not only not resolved, but also worsened in recent years.

To analyze these problems, we will use data from 2012 as the last period for which the Ministry of Natural Resources of Ukraine published the "National report on the state of the natural environment of Ukraine in 2012". For 2013 and 2014, there are no such detailed statistical and analytical reports. In general, in Ukraine, the system of statistical data on the state of the environment is in the stage of formation. Objective control is carried out on a territorial basis, not on a branch basis. System monitoring is established mainly based on the state of atmospheric air. There is no comprehensive monitoring of the ecological impact of the main polluters of the environment (to which PEK enterprises belong) in temporal and spatial dimensions. It is replaced by episodic fragmentary environmental surveys.

An important positive in the activity of the economic complex of Ukraine should be attributed to a significant decrease (by 36% - from 0,98 kg of energy consumption/UAH to 0,621 kg of energy consumption/UAH) for the period from 2000 to 2012 in the energy intensity of domestic gross product (GDP). However, this result is mainly the result of structural changes in GDP and its positive dynamics, and not technological modernization of the main industries.

PEK of Ukraine is both a producer of energy resources and a significant consumer state.

PEK is the biggest polluter of atmospheric air among all sectors of the economyof these energy resources. Its energy consumption is up to 9% of the total in the . In 2012, its enterprises for the production, distribution of electricity and gas accounted for 1,882,7 thousand tons of emissions (excluding carbon dioxide). In 2012, this group of enterprises increased emissions into the atmosphere by 4.2%. Enterprises of the extractive sector of PEK emitted 772.9 thousand tons of pollutants into the atmosphere in 2012 (4% more than in 2011). In total (excluding oil refining), PEK enterprises emitted harmful substances into the atmosphere in 2012 with a total mass of 2,655.6 thousand tons, which is 61,3% of all pollutant emissions by economic entities of Ukraine (for reference: from a total of 8,434 enterprises of all industries, the total emission of polluting substances into the atmosphere amounted to 4335,3 thousand tons).

According to the data of the State Statistics Service of Ukraine, in 2014, in terms of sectors of the economy, the largest share of emissions of pollutants and carbon dioxide falls on the production and distribution of electricity, gas, and water - 43,8% and 54,7%, respectively. The second polluter by volume is the processing industry: it accounts for 30,4% of emissions of pollutants and 39,3% of emissions of carbon dioxide. In particular, the share of metallurgy in the total volume of emissions of polluting substances in the country is 25,1%. In turn, the extractive industry accounts for 17,5% from total emissions of pollutants into the atmosphere (Table 3).

Thus, in terms of production and technological processes, as well as technological equipment, the main polluters of atmospheric air are energy companies (56,4% of all emissions into the atmosphere from stationary sources of pollution in 2014) (Fig. 10, Fig. 11).

The above data confirm the relevance of our research for understanding the real state of affairs and ways of its further improvement. That is, the pursuit of profits by the state and the new owners of privatized PEK enterprises takes place with a complete disregard for ecological reality and environmental prospects. Without a real, rather than declared, reform of the PEC on the basis of its technological modernization, the environment of Ukraine is threatened with systemic destruction, and the population expects an increase in lung, cardiovascular and oncological morbidity.

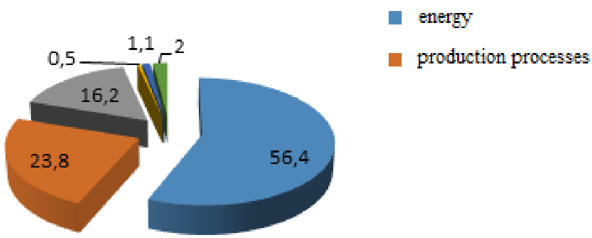

Fig. 10. Emissions of pollutants into the atmosphere from stationary sources of pollution in terms of production and technological processes, technological equipment in Ukraine in 2014

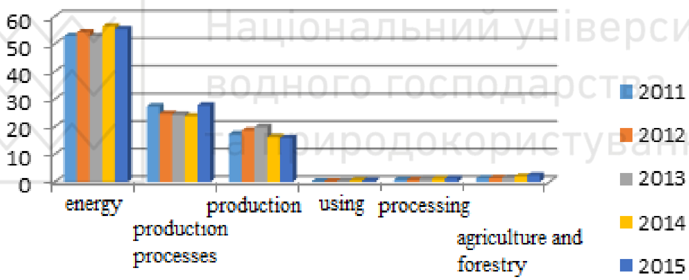

Fig. 11. Emissions of pollutants into the atmosphere from stationary sources of pollution in Ukraine in 2011-2015

In this regard, the example of the Carpathian city of Burshtyn (Ivano-Frankivsk region) is illustrative. The thermal power plant located there is part of Zahidenergo PJSC (now privatized by DTEK). Technologically, it consists of 12 power units with a capacity of 200 MW each, commissioned in 1965-1969. The total capacity of the station is 2400 MW. The main technological fuel is coal from domestic coal basins. On July 1, 2002, the industry ministry launched an experiment at the TPP: the so-called "Burshtyn Energy Island". Its essence is the separation of TPP from the unified energy system of Ukraine and parallel work with the unified energy system of European countries (UCTE) for the export of electricity.

The main consideration here was the favorable geographical location of the station - proximity to the state border, a short length of power grids leading to the EU, which means - small technological losses of electricity during its transportation. At the same time, neither the age of the equipment nor the fact that work in such conditions requires the inclusion of 6 out of 12 available blocks for loading, and not a maximum of 9, as was the case before, was not taken into account. As a result, there is an increase in the number of accidents at power units due to more intensive operating conditions. And in terms of ecology, the consequences for Burshtyn and its surroundings are much more critical.

Table 3

Volumes of emissions of pollutants from stationary sources of pollution in 2011-2015 by types of economic activity

Types of economic activity	Volumes of emissions in 2011				Volumes of emissions in 2014				Volumes of emissions in 2015			
	pollutants		*Carbon dioxide*		*pollutants*		*Carbon dioxide*		*pollutants*		*Carbon dioxide*	
	thousand tons	in % to the total	thousand tons	in % to the total	thousand tons	in % to the total	thousand tons	in % to the total	thousand tons	in % to the total	thousand tons	in % to the total
In total	4374,6	100,0	202222,0	100,0	3190,4	100,0	153119,4	100,0	2857,4	100,0	138932,1	100,0
Agriculture, forestry and fisheries	74,7	1,7	824,6	0,4	77,0	2,4	775,0	0,5	77,7	2,7	1110,4	0,8
Mining and quarrying, including:	856,2	19,6	3795,6	1,9	556,8	17,5	2753,5	1,8	490,9	17,2	2519,4	1,8
extraction of stone and brown coal	743,3	17,0	2340,1	1,2	424,7	13,3	529,2	0,3	424,7	14,9	384,0	0,3
extraction of metal ores	112,9	2,6	1455,5	0,7	96,4	3,0	1374,4	0,9	96,4	3,4	1207,4	0,9
extraction of other minerals and development of quarries	X	X	X	X	7,9	0,2	44,4	0,0	7,9	0,3	74,6	0,1
Processing industry, including:	1387,4	31,7	89501,1	44,3	968,7	30,4	60169,8	39,3	941,4	32,9	57426,6	41,3
production of food products, beverages and tobacco products	31,9	0,7	2674,3	1,3	39,7	1,2	2522,8	1,6	38,3	1,3	2005,4	1,4

Continuation of Table 3

production of coke, oil refining products	93,2	2,1	5749,9	2,8	43,8	1,4	3447,1	2,2	43,8	1,5	3034,1	2,2
chemical production	67,8				17,7	0,6	4245,7	2,8	17,7	0,6	4388,1	3,2
production of other non-metallic mineral products	55,3				33,7	1,0	5406,2	3,5	33,3	1,2	5642,1	4,1
metallurgical production and production of finished metal products	1102,3	25,2	64073,1	1,5	7190,7	3,6	42468,0	27,7	870,7	30,5	40544,5	29,2
Supply of electricity, gas, steam and air conditioning	1805,3	41,3	100537,6	1,2	7035,7	3,5	83782,8	54,7	1174,3	41,1	72250,6	52,0
Construction	20,3	0,5	601,8	0,3	4,6	0,1	614,3	0,4	3,4	0,1	467,7	0,4
Transport, warehousing, postal activities	195,4	4,5	5711,0	2,8	123,3	3,9	3231,9	2,1	76,3	2,7	2419,1	1,8
Other types of economic activity	35,3	0,8	1250,3	0,6	54,1	1,7	1723,0	1,1	55,1	2,0	2377, 6	1,7

In particular, emissions of TPP pollutants into the atmosphere increased by almost one and a half times over 12 years (Fig. 12).

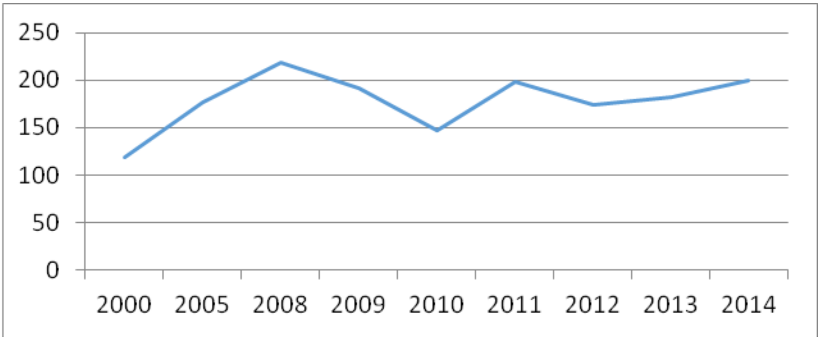

Fig. 12. Emissions of pollutants into the atmospheric air in the city of Burshtyn, thousand tons

In 2012, Burshtyn accounted for 4% of harmful emissions into the atmosphere from the total number of them in Ukraine as a whole. The town of 16,000 people was second only to Mariupol, Kryvyi Rih and Zelenodolsk in terms of this indicator. By the way, Zelenodolsk (population 15,000) has no less problematic environmental dynamics. DRES-2, located near Kryvorizka, has increased the volume of emissions of pollutants into the atmosphere by 2,8 times (from 79,4 to 219,3 thousand tons) in 12 years. In both cities, it was the powerful PEK enterprises that caused the extremely difficult environmental condition.

PEK enterprises (especially the coal industry) are the biggest polluters of water bodies. In 2012, they discharged 295 million cubic meters of polluted wastewater without treatment, which was a third of the total corresponding indicator of the industry, in 2013 – 307 million cubic meters of polluted wastewater. Unfortunately, in 2014, the State Statistics Service does not provide data on the volume of discharge of polluted return water into surface water bodies by enterprises of economic sectors (including the coal industry), limiting itself to information on the discharge of contaminated, insufficiently purified return water by region.

Specific negative features of the impact on the environment are characteristic of certain branches of PEK. In particular, enterprises producing fuel and energy minerals are the main "suppliers" of carbon dioxide into the atmosphere - 2884,4 thousand tons in 2012, which is 23,2% more than the level of 2011. Methane emissions also increased by 5,4% and totaled 633,6 thousand tons. Emissions of nitrogen and sulfur compounds practically do not decrease and are accounted for in the total amount of up to 30,000 tons.

The danger of subsidence of the surface above mine workings does not decrease. In Ukraine as a whole (in Volyn, Dnipropetrovsk, Donetsk, Luhansk and Lviv regions), this negative phenomenon covers an area of 2,4 thousand square kilometers. The microdistricts of Donetsk, Makiivka, Horlivka, Yenakievo, Novovolynsk, Sokal, and Chervonograd are in dangerous zones.

In 2012, coal and peat mining enterprises accumulated 44,4 million tons of industrial waste (10% of the total by industry), and the total volume of accumulation is 3,4 billion tons (23,1% of the total by industry) and has a steady growth trend. Half of the liquidated coal enterprises of Ukraine are located on the territory of Donetsk region - 50 mines and 2 beneficiation factories. On the balance sheet of the State Enterprise "Donvuglerestructuring" in the settlement zone of settlements there are 180 rock dumps, 49 of which are burning. Their area is 958,4 hectares. The situation is similar in Luhansk region.

The state of affairs in the nuclear power industry with the management of radioactive waste requires special attention. This issue receives insufficient attention both from relevant ministries and agencies, as well as from environmental activists and the general public. There is no closed technological cycle for the processing of radioactive waste in the PEC of Ukraine. All operating nuclear power plants have their own temporary storage facilities for spent fuel and radioactive waste. Their filling is on average 60%. Repositories of liquid radioactive waste are 20-80% full. These storage facilities are temporary and are not designed for long-term storage and increase in the volume of radioactive waste. For example, about 200 tons of irradiated and fresh nuclear fuel mixed with other components are concentrated at the "Shelter" facility of the decommissioned Chernobyl NPP.

The volume of radioactive waste in Ukraine is predicted to grow due to:

- the return to Ukraine of highly active radioactive waste after the processing in Russia of spent nuclear fuel from Ukrainian nuclear power plants;

- operation of existing nuclear power plants due to the extension of their operating period, commissioning of new nuclear power units;

- accumulation of radioactive waste in temporary storage;

- the absence of a really working modern infrastructure for the processing, storage and disposal of radioactive waste.

In general, during the years of Independence, having a tragic example of previously committed criminal negligence (Chernobyl NPP), all governments of Ukraine postponed solving the problems of handling radioactive waste for an indefinite future. For a country with 15 working nuclear reactors of 4 NPPs and technological dependence on radioactive waste processing from Russia, the absence of an appropriate specific state program may lead to new catastrophic consequences in the near future.

Serious environmental problems are not solved by the production of nuclear fuel. In the city of Zhovti Vody of the Dnipropetrovsk region (the only uranium ore mining center in the country), the population has been living under conditions of technogenic radiation pollution since the 1950s. On the territory of the city, there are more than 400 local areas with a radiation background 5-20 times higher than the natural background. Air, water, and soil are contaminated with radionuclides. In residential premises, the concentration of radon exceeds the permissible standards by several times. The city has accumulated 50 million tons of waste, including 1.4 million tons of toxic I-IV hazard classes. In general, in the region where uranium ore is mined and primary processed, in addition to Zhovty Vody, similar problems occur in the cities of Dniprodzerzhynsk, Kirovohrad and the 7th districts of Kirovohrad and Dnipropetrovsk regions. To reduce the radiological contamination of the mentioned territories, the government should urgently develop and finance a state program to increase the level of radiation safety in the uranium mining industry.

So, as we can see, the fuel and energy complex of Ukraine does not meet the requirements for the energy complex of an independent state: two fundamental principles of energy are significantly violated, namely, reliable, sustainable energy supply and efficient use of energy resources. Due to the inconsistent activity of the state authorities, not only was the improvement and optimization of the PEC not carried out, but also there was a significant deterioration of its technical condition, technological and raw material external dependence, as well as an increase in the negative man-made impact on the environment, despite a significant reduction in the volume of extraction, production and consumption of energy resources in Ukraine.

2. Provision of an innovative model of national energy development by strengthening environmental regulation

In the previous sections of the work, the state of the PEC of Ukraine as a systemic nature user was considered, the directions of its development from the point of view of ensuring the energy security of Ukraine were assessed, an ecological and economic approach was applied to the analysis and selection of the optimal solution during expert evaluations of new energy technologies. At the same time, the dominant emphasis in our research was on the interaction of the PEK with the environment, on the factors and influences manifested in the process of this interaction, which, in our opinion, meets modern requirements, corresponds to European approaches and the main provisions of the strategy of sustainable development that is relevant for modern civilized society. development

It should be noted that today the innovative direction of development is a basic strategy for business, where knowledge together with social capital create competitive advantages of individual countries and regions to a greater extent than their natural resources. Innovative processes are becoming the main source of economic growth, especially in the context of the modern paradigm of sustainable development and limited natural resources, including energy. Qualitative technological and organizational changes are the basis of innovation.

According to the Law of Ukraine "On Innovative Activity", innovations are newly created (applied) and (or) improved competitive technologies, products or services, as well as organizational and technical solutions of a production, administrative, commercial or other nature that significantly improve the structure and quality of production and (or) the social sphere.

Given that there is a significant share of natural monopolies in the energy industry, one should understand the special role of state authorities in organizing and stimulating the innovative activities of

PEK enterprises. Legislation provides for sufficiently wide application of methods of state regulation of innovative activity, which should be carried out by:

- determination and support of priority areas of innovative activity at the state, branch, regional and local levels;
- formation and implementation of state, branch, regional and local innovation programs;
- creation of a regulatory and legal framework and economic mechanisms to support and stimulate innovative activity;
- protection of the rights and interests of subjects of innovative activity;
- financial support for implementation of innovative projects;
- stimulation of commercial banks and other financial and credit institutions that provide credit for the implementation of innovative projects;
- establishment of preferential taxation of subjects of innovative activity;
- supporting the functioning and development of modern innovative infrastructure.

In accordance with the Law of Ukraine "On priority areas of innovative activity in Ukraine", priority areas are defined as areas of innovative activity aimed at ensuring the economic security of the state, creating high-tech competitive environmentally friendly products, providing high-quality services and increasing the export potential of the state with the effective use of domestic and world scientific and technical achievements.

The priority directions of innovative activity in Ukraine are divided into strategic (intended for the long term - at least 10 years) and medium-term (intended for implementation within the next 3-5 years).

The strategic directions of innovative activity are legally defined for the PEC of Ukraine, the modernization of power plants; new and renewable energy sources; the latest resource-saving technologies; protection and improvement of people and the environment.

Medium-term areas of innovative activity for PEK include:

- new and renewable energy sources;
- the latest resource-saving technologies;
- modernization of power plants and power networks;

- power supply networks of nuclear power plants;
- steam and gas plants and technologies for burning low-grade solid, liquid and gaseous fuels;
- means of labor protection and improvement of safety techniques at coal mining enterprises;
- methods and methods of extraction and utilization of methane from coal deposits;
- oil and gas drilling equipment;
- modernization of gas, oil, ammonia transportation systems;
- energy-efficient light sources and lighting systems;
- energy-efficient, resource-saving, modular equipment for heat supply, water treatment, water supply and drainage.

Therefore, the legislative main task of innovative activity programs in the PEC is defined as the creation of an optimal fuel and energy balance of the state, taking into account energy security; diversification of energy supply sources and energy technologies; an increase in the share of coal and electricity consumption of nuclear power plants due to a decrease in the share of natural gas use; development and implementation of the latest coal burning technologies and TPP modernization; creation of own nuclear fuel cycle; development of the use of renewable energy sources.

It should be noted that the determination of the priority areas of the state innovation policy is only the first step on the path of systemic innovation development. The main task of state regulation of innovative activity is to create appropriate regulatory mechanisms and use their capabilities in the following areas:
- regulatory and legislative framework;
- tax policy;
- tariff and price policy;
- ensuring privatization processes;
- creation of market conditions of competition;
- attraction of investments;
- financial support.

Each of the above-mentioned directions is important and must correspond with the others. Their implementation in the conditions of

PEK can become the subject of a separate study that goes beyond the scope of our work. At the same time, we note the following regarding the financial support of the innovative activity of PEK.

Financing of innovative activities has always been one of the key problems in Ukraine. The main financial sources were supposed to be:

- own funds of business entities (at the expense of part of the profit and depreciation deductions);
- part of the funds received from the privatization of PEK facilities;
- private domestic investments;
- foreign investments;
- funds of the Wholesale electricity market (for the electric power industry);
- state financial support.

Since 2010, government financial support has mainly been provided through the branch ministry as the main fund manager for applied research by branch research institutions. Thus, the total budgetary financing of innovative activity and technology transfer for 2012 in Ukraine amounted to UAH 222,8 million, including UAH 58,5 million for the Ministry of Energy and Coal. (26,2% of the total volume).

Taking into account the technological level of PEK, the total need for innovative financing (according to experts' estimates) is from UAH 8 to 12 billion annually. Economic entities will not be able to obtain such financial resources by their own efforts without targeted foreign investment. Therefore, the problem of creating an attractive investment climate in the PEK of Ukraine for the activation of innovative processes has acquired special importance.

As noted by specialists of the National Institute of Strategic Studies, in order to increase the investment attractiveness of the innovative PEK market of Ukraine, it is necessary to implement a consistent set of measures for rational environmental management.

Achieving the specified levels of basic indicators requires not only intensification of investment activity.

In the end, the environmental regulation of the work of the PEK (as well as other branches of the economic complex) requires the construction of a new system of relationships in the chain: central government - regional government (local self-government) - business entity.

However, the dominant role of the central authorities in the implementation of the system of economic and environmental regulation and control over this process has objectively encountered insurmountable difficulties in the current conditions, namely: lack of effective and objective environmental monitoring; unsatisfactory control over the implementation of state environmental programs and a formal approach to monitoring the implementation of regional environmental programs.

At the same time, regional authorities and local self-governments (in contrast to similar structures of EU member states) do not consider ecological problems of their territories as absolutely priority issues, paying mainly attention to socio-economic issues, the state of housing and communal services, employment of the population.

Conclusions

We believe that in the conditions of reforming local authorities through decentralization and transfer to them of a significant part of powers from the central government, the creation of executive committees at the level of regional and district councils, there are favorable circumstances for strengthening the environmental component at the local level by developing truly relevant target programs adapted to the real state of the environment in each settlement, taking into account environmental monitoring and the activities of the located business entities.

This approach, in our opinion, will best stimulate business entities to a consistent innovation process to reduce harmful emissions and other destructive effects on the environment to regulatory requirements for the purpose of rational environmental management.

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IMPROVEMENT OF THE INVESTIGATION OF PHYSICAL AND MECHANICAL CHARACTERISTICS OF SEDIMENTARY ROCKS BY EXPRESS METHODS

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Abstract

Field and laboratory express methods for studying physical and mechanical parameters of sedimentary rocks (penetration, static sounding, rotational displacement), as well as traditional methods of evaluating their mechanical properties, are considered. The peculiarities of detecting these characteristics for cohesive and non-cohesive sedimentary rocks are clearly divided. Theoretical prerequisites have been confirmed by experimental studies. It is proved that the objective credibility criterion of the reliability of the penetration and sounding characteristics is their invariance, embedded in the limit equilibrium equation. The method of determining the strength of sands based on the results of penetration and sounding has been developed. For cohesive rocks, a method of combined testing by penetration and rotational shear is proposed for this. The results of experimental studies are presented, which confirm the sufficient convergence of the values of strength parameters obtained by standard and express methods. The generalization of experimental data is proposed according to the calculation schemes of the relationship of the properties of sedimentary rocks.

Keywords: sedimentary rock, penetration, sounding, rotational displacement, invariance, equations of limit equilibrium, strength, relationship.

Introduction

To correctly determine the physical and mechanical properties of sedimentary rocks, complexes of their laboratory and field tests were conducted [1].

However, these complexes are usually quite time-consuming and long. Therefore, a promising direction for studying the characteristics of sedimentary rocks is the introduction of so-called express methods [2-6]: in the laboratory, this is penetration and rotary cutting, and in field conditions - sounding.

Thus, penetration is widely used for the classification of cohesive rocks (clay, loam, sandy loam) [7-10], penetration and sounding - for evaluating the strength of non-cohesive rocks (sands) [11-13], combined penetration and rotary section tests - for a similar problem of determining the strength of cohesive rocks [13-16].

Express methods have also been tested for a number of mining and geotechnical problems, for example, penetration - to estimate the parameters of the anisotropy of the environment [17,18], as well as the study of mechanical properties of rocks under special conditions, in particular, static sounding - to determine the strength of marine sediments [19-21], etc.

1. Interpretation of the investigation results of the physical and mechanical rock properties by express methods

Processing of experimental data was carried out according to the calculation schemes of the relationship of the properties of rocks, the theoretical base of which was developed under the guidance of V. Razorenov [3].

Ultimate force on a conical tip with an angle between the generatrix and the vertical α=15° with axisymmetric loading is determined by the three-term formula

$$F = U_o\gamma_1 h_c^3 + V_o\gamma_1 h_c^2 + N_o c_1 h_c^2; \text{ kN} \quad (1)$$

where U_0, V_0, N_0 - coefficients of the equation depending on the angle of internal friction of the sedimentary rock φ_1^0; γ_1- specific weight of the breed, kN/m^3; specific adhesion, kPa; h_c - height of the conical part of the tip, m; H - depth of the base of the cone from the earth's surface, m.

If the depth of immersion of the conic tip, h, is less than its height, h_c, the process of rock penetration occurs. With H=0 and the expression (1) takes the form

$$F = U_o\gamma_1 h^3 + N_o c_1 h^2; \text{ kN.} \quad (2)$$

The specific resistance of penetration, R, which is the ratio of the penetration force, F, to the square of the depth of immersion of the tip into the rock, is taken as a parameter of penetration tests [3]

$$R = \frac{F}{h^2} = U_o\gamma_1 h + N_o c_1; \text{ kPa.} \quad (3)$$

Let us consider three possible cases of using the equation (3).

Case 1: When $\varphi \neq 0$, C=0 it is characteristic of air-dry and completely water-saturated sands

$$R = U_o\gamma h; \text{ kPa.} \quad (4)$$

The penetration index was proposed as a characteristic of the penetration tests of these sands

$$U = \frac{R}{h} = \frac{F}{h^3} = U_o\gamma; \text{ kN/m}^3. \quad (5)$$

Graphs of invariance of shallow, quartz sand with a low degree of water saturation are shown in Fig. 1*a*.

The penetration index is defined as the tangent of the angle of inclination of the averaged straight line to the ordinate axis.

Case 2: when $\varphi \leq 24°$ and $C \neq 0$ characteristic of clay soils. With small sizes of conical tips (up to 100 mm), the first term of equation (3) does not exceed 5% of the total value of specific penetration resistance. It can be neglected.

Then

$$R = \frac{F}{h^2} = N_0 c \text{ , kPa.} \tag{6}$$

Graphs of the invariance of the specific penetration resistance are shown in Fig. 1*b*.

Case 3: When $\varphi > 24°$, $C \neq 0$; characteristic of sands and loams. If $R_0 = N_0 C_1$ is accepted, then expression (3) taking into account (5) can be written as

$$R = R_o + Uh \text{ , kPa.} \tag{7}$$

The graph according to equation (7) is presented in Fig. 1*c*.

Shown in Fig. 1 of the penetration graphs indicate the invariance of the penetration index, *U*, or the specific penetration resistance, *R*, i.e., the correspondence to the averaged straight line of the equation describing one of the cases of penetration.

If the condition of invariance is violated, that is, the test points deviate from the averaged straight line, this indicates factors that are not taken into account by the calculation scheme and their nature should be explained.

This can be the effect of the ring walls, the heterogeneity of the rock in terms of penetration depth, malfunction of the penetrometer, etc.

Plotting the invariance, *U*, or, *R*, is usually done during the tests themselves. This allows timely detection of deviations from the accepted calculation scheme that were not foreseen by the experiment.

Rotational section is a method of studying the mechanical parameters of soils by determining the resistance of the soil to the rotation of wing tips formed by two intersecting planes.

When testing soils from the earth's surface, when the winged tip is immersed in the soil only to its height, the self-weight of the soil can be neglected and the ultimate resistance of the rotary section can be taken as equal to the specific adhesion of the soil, *C*.

The ultimate resistance of the rotary section is defined as the ratio of the maximum moment of the rotary section, M_{max}, to the static moment of the cut surface,

$$\tau = \frac{M_{max}}{K_\tau} \tag{8}$$

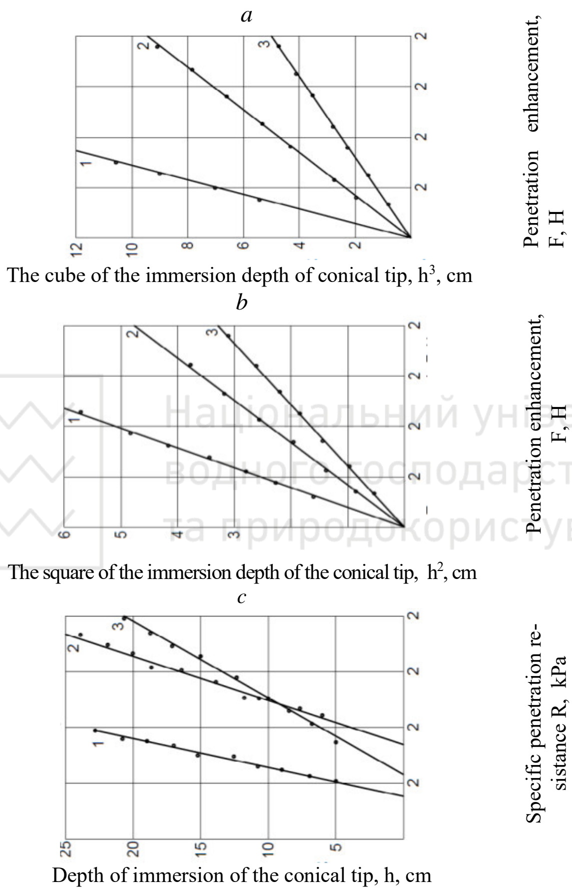

Fig. 1. Penetration graphs: *a* - sands: u_1 = 0,29 mN/m^3; u_2 = 0,84 mN/m^3; u_3 = 1.6 mN/m^3; *b* - loam: R_1 = 7,8 кПа; R_2 = 16,8 kPa; R_3 = 24 kPa; *c* - loams: R_{01} = 16 kPa; R_{o2} = 22 kPa; R_{03} = 35 kPa

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When the wing tip is immersed in the soil only to its height, the cut is made along the cylindrical and lower circular surfaces, then is determined by the formula

$$K_{\tau} = \frac{AD^2}{2}\left[\frac{D}{6} + h\right], \quad (9)$$

where *D* and *h* - diameter and height of the wing tip.

When penetrating clayey soils in case 2, the specific penetration resistance is proportional to the specific adhesion. Solving equation (6), we get

$$C = \frac{1}{N_o}R = K_{\varphi}R. \quad (10)$$

As a derivative of the carrying capacity coefficient, N_0, limit equilibrium equation (1) coefficient $K_{\varphi}=f(\varphi°)$ and is equal to

$$K_{\varphi} = \frac{C}{R}. \quad (11)$$

Sounding is a method of studying the properties of rocks by determining the reactive resistance of the rock to the conical tip when it is immersed to a depth exceeding the height of the cone h_c.

In the equation (1) $H\neq0$.

Consider a type of static sounding of rocks, when the ratio of the diameter of the cone to the diameter of the rods $(d_c/d_m)\geq 1{,}6$.

In this case, in addition to the complete or partial removal of friction on the side surface of the rods, the rock protrudes into the cavity between the rod and the well wall. In this case, in addition to the complete or partial removal of friction on the side surface of the rods, the rock protrudes into the cavity between the rod and the well wall.

For cohesive rocks at the value of the angle of internal friction $\varphi<20°$ the first two terms of the expression (1) do not exceed 5% of the total value, So,

$$F = N_o c_1 h^2 . \quad (12)$$

As an objective characteristic of the results of static sounding of cohesive rocks, the specific resistance of sounding is used *Q*

$$Q = \frac{F}{h_c^2} = N_o C \quad . \quad (13)$$

The invariance of the specific resistance of sounding in a layer of homogeneous rock is manifested in the fact that the sounding force in it remains constant.

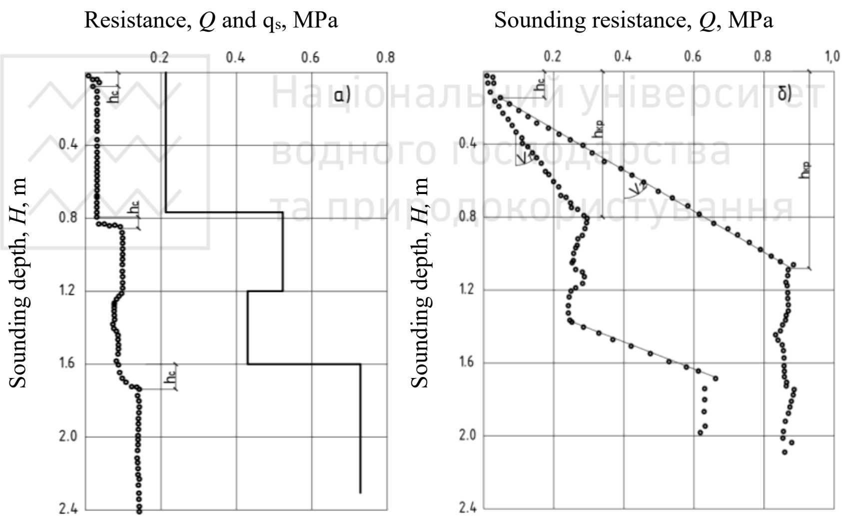
On the sounding graph, this is expressed by a straight line parallel to the ordinate axis (Fig. 2*a*).

Comparing equations (6) and (13), we can write that

$$Q = R = N_o C \quad . \tag{14}$$

The values of the specific resistances of sounding and penetration of cohesive rocks are equal to each other due to the free protrusion of the rock from under the cone during penetration - to the surface, during sounding - into the borehole cavity.

The effect established by the results of numerous comparative tests allows the results of penetration tests to be widely used also in the analysis of data of static sounding of rocks with an extended conical tip.



a *b*

Fig. 2. Graphs of sounding: *a* - loam of rigid plasticity:
1 - Q=f(H); 2 - $Q_s f(H)$; b - shallov, loose sands $V_3 = 0{,}34\,\frac{MPa}{m}$; medium density

$$V_2 = 0{,}488\,\frac{MPa}{m}\ ; \ V_{23} = 1{,}3\,\frac{MPa}{m}$$

Sometimes it is convenient to use the resistance value of the cone rock, q_s

$$q_s = \frac{F}{A} = 4.433Q \quad , \tag{15}$$

where A is the area of the base of the conical tip.

For non-cohesive rocks at $C = 0$ (air-dry and water-saturated sands), the sounding process is described by the first two terms of equation (1), with the first term representing a constant value.

It is proposed to use the sensing index as the sensing characteristics of such rocks V

$$V = \frac{Q_1 - Q_2}{H_2 - H_1} = V_o \gamma \quad . \tag{16}$$

In a layer of homogeneous rock, the invariance of the sounding index is manifested in the fact that the specific sounding resistance Q increases linearly with the depth of sounding with the angular coefficient V - the sounding index (Fig. 2*b*).

The established regularity in a layer of homogeneous sand will manifest itself up to a depth called critical. Below this depth, when the rock is homogeneous, the specific resistance to sounding does not change.

The value h_{cr} depends on the density of the sand and the size of the conical tip. The greater the density of the sand and the greater the diameter of the base of the cone, the more h_{cr} is. Similar regularities were observed [11,12] during the immersion of piles and their models.

The following studies established a connection between the characteristics of high-speed research methods and the physical and mechanical properties of rocks.

2. Express determination methods of physical and mechanical rock properties

General expression for determining the force on a conical tip with an angle between the generatrix and the vertical α=15° during penetration and sounding are given in (1). The physical characteristics in (1) are represented by the specific gravity of the rock γ. Strength characteristics are in the form of specific adhesion C and bearing capacity coefficients U_0, V_0 and N_0, which depend only on the angle of internal friction φ. The bearing capacity coefficients of equation (1) can be determined on the basis of the solutions of the axisymmetric problem of the theory of limit equilibrium, performed, including for conical stamps with an angle α=15°, by V. Berezantsev [3]. In Fig. 3 shows the dependence of the coefficients U_0, V_0 and N_o on the angle of internal rock friction φ.

For the convenience of using these dependencies, they are presented in the form of correlation equations with the corresponding statistical indicators

$$\varphi^{\circ} = 25{,}03 + 6{,}1 \ln U_o\,; \tag{17}$$

variance 0,15; coefficient of variation v = 0,014

$$\varphi^{\circ} = 15.0 + 7.03 \ln V_o\,; \tag{18}$$

variance 0,17; coefficient of variation v = 0,03

$$\varphi^{\circ} = 7.75 + 9.8\, lnN_o\,; \tag{19}$$

variance 0,18; coefficient of variation v = 0,02

$$\lg tg\varphi = -1.29 \lg k_{\varphi} - 1.276\,; \tag{20}$$

variance 0,12; coefficient of variation v = 0,014.

Fig. 3. Graphs of dependence of bearing capacity coefficients U_0,V_0,N_0 on the angle of internal friction φ°

To determine the strength characteristics of sandy loams and sands, when their angle of internal friction is more than 24°, a penetration test method with a tip height h_c=25 cm. Such studies can be carried out only in field conditions using mechanized penetration units, which allow the tips to be immersed in the array at a speed of no more than 0,5 m/min. The sequence of operations for determining rock strength characteristics is as follows.

1. At a given depth in a trench or pit, the surface of the array is cleaned and penetration tests are performed with height tips. h_c=25 cm and the angle α=15° in a quantity sufficient for statistical generalization (at least 6).

2. In parallel with the penetration tests, the density-moisture of the test rock is determined.

3. The results of each penetration test are presented in the form of a linear relationship (7) with the use of computer programs, with the help of which the values are set R_0 and U_0 with determination of their dispersion and coefficient of variation. According to statistical indicators, the obtained results are rejected.

4. Using equation (17), the angle of internal friction is determined by the value of U_0, φ.

5. Specific adhesion is defined as a ratio

$$C = \frac{R_o}{N_o}. \tag{21}$$

where N_0 is set according to equation (19) according to the already known value of the angle of internal friction.

In the Table 1 shows the data for the determination of the angle of internal friction φ and the specific adhesion *C* of quartz, fine sand, of medium density, saturated with water at the site in the city of Kremenchuk on the right bank of the Dnieper according to the data of penetration tests.

Table 1

Calculated data for determining the angle of internal friction and ideal sand adhesion of the site by the penetration method

Conditions of the experiment	Number of trials	Coefficient of water saturation	Specific gravity of the soil, γ		Penetration rate	
			γ, kN/m^3	Coefficient of variation, *v*	*U*, H/cm	Coefficient of variation, *v*
The water level is below the surface of the rock	47	0,92	20,1	0,13	7,2	0,18
The water level is above the rock surface	54	1,00	10,5	0,11	3,15	0,17

Conditions of the experiment	Indicator U_o	Angle, φ°	N_o	Parameter		Specific cohesion, *C*, kPa
				R_o, kPa	coefficient of variation, *v*	
The water level is below the surface of the rock	3,44	33	18.5	25	0.16	1.4
The water level is above the rock level	3,01	32	16	13	0.15	0.8

Table data 1, as well as the results of research conducted at other research sites, show that:

1. The considered method of processing the results of sand penetration tests allows determining the strength characteristics based on the results of one immersion of the conical tip at 6-8 degrees of load.

2. The high sensitivity of the penetration method draws attention. With its help, the adhesion value of 0,8-1,4 kPa with the coefficient of variation was established *v*=0,15, which is practically impossible to achieve by the single-plane displacement method.

3. With an increase in specific adhesion and a decrease in the angle of internal friction within the limits that characterize cohesive soils, the capabilities of the proposed method certainly decrease. It is

already difficult to set the value of the penetration index U when the general characteristics R are scattered $\varphi\approx22$.

As the penetration tests of sands have shown, they can have a certain amount of cohesion. Let's consider the regularities that occur in the sand during sounding. Calculation schemes of sand penetration and sounding are shown in Fig. 4.

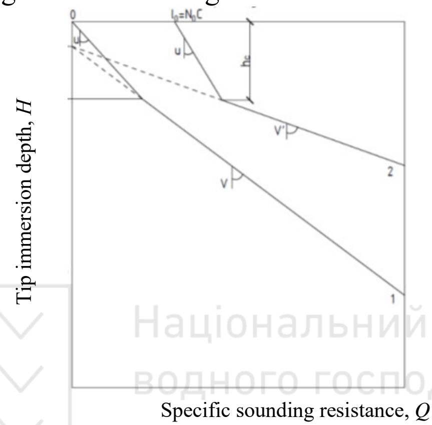


Fig.4. Schemes of sounding graphs of sands to the critical depth:
1 – at C=0; and *2* – at $C\neq0$

When C=0, the sounding indicator

$$V=\frac{Uh_c}{h_v}. \tag{22}$$

In the presence of cohesion, the graph of the penetration index shifts parallel to the right from the origin of the coordinates

$$V'=\frac{R_o+Uh_c}{h_v}. \tag{23}$$

Dividing both parts of (23) by expression (22), we get

$$\frac{V'}{V}=\frac{R_o}{U}\times\frac{1}{h_c}+1. \tag{24}$$

It follows from this that the systematic error in the sounding index is a linear function of the soil specific adhesion C.

As the angle of internal friction increases, the systematic error in the sounding index, V', due to adhesion will noticeably decrease.

The value of the absolute error can be calculated using the formula

$$\Delta V = V' - V = \frac{R_o}{h_v}. \tag{25}$$

Therefore, for cohesive sands, the sounding index, V', is defined as the tangent of the angle of inclination of the sounding graph to the ordinate axis below the depth of penetration, is a function of the angle of internal friction, φ, and the specific adhesion, C.

This provision makes it possible to solve the problem of determining the characteristics of the strength of sandy soils based on the data of static sounding with conical tips of two different sizes. Then, accordingly, $V_1 < V'_2$ and the differece between them will be

$$V_1' - V_2' = \frac{R_o}{\frac{U}{V}}\left[\frac{1}{h_{c2}} - \frac{1}{h_{c1}}\right]; \tag{26}$$

or

$$\frac{R_o}{\frac{U}{V}} = \frac{V_1' - V_2'}{\frac{1}{h_{c2}} - \frac{1}{h_{c1}}}. \tag{27}$$

On the basis of (25), the equality can be established

$$\Delta V_1 \times h_{o1} = \Delta V_2 \times h_{o2}; \tag{28}$$

then

$$\left.\begin{aligned} \Delta V_1 &= V_1' - V = -\frac{V_2' - V_1'}{\frac{h_{c1}}{h_{c2}} - 1} \\ \Delta V_2 &= V_1' - V = -\frac{V_2' - V_1'}{1 - \frac{h_{c2}}{h_{c1}}} \end{aligned}\right\}. \tag{29}$$

It can be seen from expression (29) that the corrected value of the sounding indicator is equal to the measured value $V_1'(V_2')$ minus the systematic error

$$V = V_1' - \Delta V_1 = V_2' - \Delta V_2. \tag{30}$$

With a known value of soil specific gravity γ, the generalized sounding indicator V_o is

$$V_o = \frac{V}{\gamma}. \tag{31}$$

With a known value of soil specific gravity γ, the generalized sounding indicator V_0 is and $U_0;N_0$.

The specific cohesion can be determined as a result of the transformation of the formula (3.25)

$$C = \frac{U_0}{V_0 N_0} \Delta V_1 \times h_{c1} \tag{32}$$

The considered method of determining the strength of sands based on the data of static sounding with an extended conical tip with an angle between the vertical and horizontal α=15° is widely used in engineering and geological surveys.

In the Table 2 shows some data of such definitions.

Attention is drawn to the close convergence of the strength values established for the site in Kremenchuk, based on the results of penetration and sounding tests of fine watered sand.

The method of combined tests of cohesive soils by penetration and rotary section allows determining the angle of internal friction φ and the specific adhesion *C* of clay rocks in the field and in the shortest possible time in a quantity sufficient for statistical processing.

For combined tests in the field, mechanized static sounding installations, additionally equipped with devices for rotary cutting, are used.

Preferably, separate tips are used for penetration in the form of a cone with an angle between the vertical and vertical α=15° and for a rotational section in the form of two planes intersecting at an angle of 90°.

During the study on each horizon, the points of penetration and rotational section are arranged in a staggered order with a distance between adjacent points of at least $6D_c$, where D_c - diameter of the base of the cone.

The equation of the relationship between the physical and mechanical properties of sedimentary rocks is established for their individual varieties, which have constant indicative parameters (for example, plasticity number, mineralogical composition, structural features, etc.), by means of statistical processing of a sufficient sample of random values [3, 13-15].

Applying the penetration method and having the density-moisture value, it is possible to determine the required characteristic in any element of the array.

Table 2

Calculated data for determining the angle of internal friction and specific adhesion of sands based on static sounding data

Ground	Type of sand	Number of experiments	Tip height h_c, cm	Experimental value of the sounding indicator, U: U, kN/cm^3	Experimental value of the sounding indicator, U: coefficient of variation, v	Indicator U, kN/cm$_3$
Kherson region	medium-sized, wet	34	9,0 15,0	1,78 1,37	0,10	0,98
Kremen-chuk	shallow watery sand	129	25,0 9,0	0,35 0,72	0,16	0,11
Myko-laiiv region	large wet	40	9,0 11,0 13,3 15,0 18,4 21,9 9,0 11,0 13,3 15,0	1,20 1,06 1,01 0,92 0,91 0,87 0,31 0,27 0,26 0,23	0,09	0,65
	large watered				0,075	0,165

Soil specific gravity: γ, kN/m^3	Soil specific gravity: coefficient of variation, v	Generalized sounding indicator, V_o	Angle of internal friction, φ	Bearing capacity factor, U_o	Specific adhesion C, kPa
16,7	0,08	58,6	41,6	0,0046	0,33
10,5	0,15	10,5	32,2	0,019	1,00
17,0	0,06	38	39,4	0,0062	0,3
10,0	0,06	16,5	35	0,0126	0,4

Conclusions

The description of sounding and penetration of sedimentary rocks by the traditional three-step formula of the limit state of the massif made it possible to establish the objective parameters of penetration and sounding. The features of detecting these characteristics are clearly divided for cohesive and noncohesive rocks. Theoretical postulates have been confirmed by experimental studies.

An objective criterion for the reliability of the penetration and sounding parameters is their invariance, embedded in the limit equilibrium equation. Features of the invariance of penetration and sounding characteristics for cohesive and noncohesive rocks have been recorded. Violation of the invariance of the penetration and sounding parameters indicates the presence of factors that were not taken into account when planning the experiment. Invariance control is a way to detect them.

To determine the bearing capacity coefficients in the three-term equation of the limit state of rocks during penetration and sounding, the solution of V. Berezantsev for axisymmetric deformation was taken as a basis. Techniques have been developed for assessing the strength of sands, including those with cohesion, based on the results of penetration and sounding, and in cohesive rocks, combined penetration and rotary shear tests should be used for this. Sufficient convergence of the values of strength parameters obtained by normative and express methods was confirmed.

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DEVELOPMENT OF AN EFFECTIVE TECHNOLOGY FOR THE CONSTRUCTION OF LARGE-DIAMETER WATER WELLS

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Abstract

Subject of study. Technology of drilling large-diameter water wells with reverse circulation in the conditions of the Samskoye groundwater field.

Methodology. The tasks were solved by a complex research method, which includes a review and generalization of literary and patent sources, analytical studies of existing methods for optimizing the technological parameters of drilling with reverse circulation using an airlift.

Purpose. A sharp increase in the use of groundwater resources of the Samskoye field through the introduction of advanced technologies for drilling water wells, ensuring their maximum flow rate at high quality and at the lowest cost.

Findings. It has been established that in the study of the airlift circulation method during rotary drilling with reverse circulation, an important role is played by the analysis of the pressure balance arising in the course of drilling in the annulus and in the drill string. It takes into account both hydrostatic pressures and pressure losses for pumping water and water-air mixture. A technique has been developed for assessing the effect of rate of penetration on circulation parameters.

1.1. Introduction

Water resources play a crucial role in the economy of any country. An important resource is groundwater extracted from boreholes. The problem of the development and protection of groundwater is in the focus of attention of special UN organizations [1]. In the Republic of Kazakhstan, there is a noticeable shortage of water resources, which is a consequence of the natural features of its territory and climate. A significant part of its vast territory, including the center, south and west, belong to the zones of deserts and semi-deserts, characterized by rare precipitation and underdeveloped river networks. The earth's surface is often covered with salt marshes, and the permeable horizons close to the surface contain waters with high mineralization and cannot be used for drinking purposes.

Since 2002, the country has been consistently implementing the programs «Drinking Water» for 2003-2010, «Ak-Bulak» for 2011-2020 and the State Program for the Development of Regions for 2020-2025.

The «Drinking Water» Program started in 2002. The goal this program was the complete provision of drinking water to more than 7,000 settlements, including the installation of water supply systems in 174 villages and 86 towns. It lasted 8 years for its implementation, 195 billion tenge was allocated from the budget [2].

The second program, which was supposed to help provide Kazakhstan with clean drinking water, was launched in 2011 for a period of 9 years. The program was supposed to provide by 2020 with high-quality drinking water from centralized water supply systems the rural population of Kazakhstan by 85% and the urban population by 100%. For these purposes, it was planned to allocate a total of 1,3 trillion tenge. In 2011-2018, within the framework of the state program for the development of regions, 2015 projects were implemented from the republican budget for the development of water supply and sanitation systems [2].

Unfortunately, for a number of reasons, the implementation of these programs did not allow solving the problems of water supply in certain regions.

According to the Concept of the State Program for Water Resources Management of Kazakhstan for 2020-2030, by 2040 water consumption will increase by 56% and water deficit will be about 12 billion m^3.

Mangystau is an industrial region. The basis of the economy is the oil and gas sector. In the structure of industry, the main share is occupied by the mining industry and quarrying, the share of which at the end of 2020 amounted to 85%. The industry employs about 25% of the population of the region; the share of the industry in the gross regional product is about 50%. Regional enterprises annually produce more than 10% of the industrial output of the country [3].

Based on the current demographic situation and the development of the region as a whole, the need for water supply in the region is growing every year. The water supply of the region is carried out from the Astrakhan-Mangystau water conduit and desalinated sea water, since there are few sources of natural groundwater. To date, drinking water consumption is 149 thousand m^3/day. There is a deficit in the region's water supply in the amount of 51 thousand m^3, and given the development of the region by 2025, the need will be 250-260 thousand m^3, and the deficit will be 100-110 thousand m^3 [4].

The implementation of the 2nd stage of bringing the capacity of the desalination plant «Kaspiy» to 40 thousand m^3/day has begun. JSC NC KazMunayGas is building a plant with a capacity of 17 thousand m^3/day at the Karazhanbas field.

To supply the city of Zhanaozen in the area of Kenderli and the village of Kuryk, it is planned to build desalination plants with a capacity of 50 thousand m^3/day, and on the territory of MAEC-

Kazatomprom LLP with a capacity of 24 thousand m^3/day. It is planned to build a desalination plant with a capacity of 5 thousand m^3/day in the city of Fort Shevchenko [3].

Drinking water supply is provided by three sources and their share in the total volume of water consumption has the ratio:

- sea water - 52.4%;
- Volga water - 12.5%;
- groundwater - 35.1% [5].

1.2 Literature review

The Samskoye field is the main source of groundwater for the city of Zhanaozen. The field has been in operation since 1970. In 1979, the established total water withdrawal was only 0,02 thousand m^3/day, mainly due to private wells dug by the local population. Currently, the withdrawal of groundwater in the city of Zhanaozen has increased to 6,4 thousand m^3/day, which is 18% of the resources of the Samskoye field, although the problem of high-quality water supply to the city is still acute [6].

This problem can only be solved by significantly increasing the number of water wells and obtaining the maximum flow rate of groundwater of standard quality at the lowest cost.

Established according to the report [7] and approved for category B, the operational groundwater reserves are 21,2 thousand m^3/day for fresh water and 14,3 thousand m^3/day for slightly brackish water. The same values appear in modern documents [6].

For successful drilling of a well in the conditions of the Samskoye field, it is necessary to justify the drilling method, select drilling equipment, composition and parameters of the drilling fluid, rock cutting tools and drilling mode parameters.

As a rule, the main directions of scientific research are carried out in two main directions: solving issues related to the technology of cleaning a well from cuttings [8] and developing optimal parameters for the operation of a rock cutting tool [9,10].

Most often, drilling with direct circulation of drilling fluid is used for water wells. This technology is simple to organize, does not require additional equipment, and allows efficient use of the energy of the drilling fluid for the destruction of rocks [11].

The drilling rig is equipped with a rotator that rotates a drill string with a bit at its lower end. Destruction products are brought to the surface by drilling fluid, which is fed into the well by a drilling pump. Through the injection hose and swivel, it enters the drill pipe string, along which it moves down to the working bit. Cleaning the bit and the bottomhole, the fluid returns to the surface together with the drill cuttings, where, after being freed from the cuttings in the cleaning system, it is again sucked in by the drilling pump, thus circulating [12].

However, with this circulation method, low drilling fluid flow rate, poor particle retention, low drilling efficiency, and severe wear of the drill bit are observed [13].

Another huge problem with this method is the high time and cost involved in combating fluid losses [14].

Usually, to eliminate this complication, the installation of casing strings or plugging of the absorbing horizon in various ways is used [15]. However, when drilling wells for water, the use of these methods will only lead to unjustified expenditures of time and money.

The use of reverse circulation effectively solves the problem of drilling fluid losses in the well [16].

Reverse circulation drilling has proven to be highly effective in drilling wells for various purposes.

Thus, this method was successfully applied for the extraction of uranium ore by underground borehole leaching at operating technological wells of Volkovgeologiya, with an average total depth of 300-500 m [17].

There are examples of its use even in mine exploration instead of traditional core drilling, where reverse circulation drilling has high drilling efficiency and low cost [18].

According to [19], compared with traditional core drilling, drilling with reverse air circulation increased drilling efficiency by 70-90% while reducing costs by 30-50%, the number of accidents during drilling decreased by 60-70%. In addition, reverse circulation drilling is more environmentally friendly [20].

The reduction of accidents is the most important factor in improving the efficiency of drilling wells, since the cost of repairs significantly increases the cost of well construction [21].

Airlift reverse circulation drilling showed high efficiency when drilling geothermal wells [22].

The application of airlift reverse circulation drilling technology is possible even in the construction of wells with a depth of 4200 m, which is the deepest geothermal well in China [16].

Note that another possible application of reverse circulation with the help of an airlift is not drilling a well, but expanding it with the help of jet jets [23].

The experience of using this technology in drilling wells for gas hydrates is also known [24].

Thus, in recent years there has been a steady trend towards expanding the scope of drilling wells with reverse circulation of drilling fluid. This is due to the fact that this method has a number of significant advantages.

Thus, the use of reverse circulation drilling allows drilling wells with a diameter of up to 1500 mm [25].

Reverse circulation drilling technology is much more efficient, has better technical support and will play an increasingly important role in water well drilling in the future [26].

There are many difficulties in well drilling with groundwater and large diameter wells with direct circulation of drilling fluid. The main reason for this is that due to the large drilling diameter, there are problems with cuttings to the surface, which can lead to well failure, long drilling period and high cost. The use of the reverse circulation process can effectively increase the rate of penetration (ROP), reduce the cost of the project, and reduce the labor intensity of the process. Due to the high rate of the upward flow of the drilling fluid (usually above 2 m/s), large diameter cuttings can be brought to the surface, and therefore, the ROP can be increased. Using this method, the ROP increases by about 30% compared to direct circulation drilling [27].

Analyzing the cost of drilling wells, researchers identify three characteristic trends:

1. Well costs increase exponentially with depth due to more difficult drilling conditions.

2. Well cost uncertainty increases with depth due to increased likelihood of problems and less predictable drilling conditions.

3. Deep wells have a positive cost probability distribution [28].

Thus, it is very important to maximize the speed of well construction through efficient drilling technology.

The key parameters of the drilling technology with reverse circulation and airlift gas injection are the volume of gas injection and displacement of the drilling fluid, the change of which regulates the bottomhole pressure [29].

It should be noted that reasonable recommendations do not include a choice of parameters for reverse circulation mechanisms and a large number of design flaws hinder the wide practical application of this drilling method [30].

1.3. Geological, geophysical and hydrogeological knowledge of the work area

1.3.1. Physical and geographical characteristics

The described territory is characterized by a very low water supply and an extremely tense water balance. Water supply of national economic objects is carried out at the expense of surface and underground waters. In the 1960s and early 1970s, water conduits Guryev-Sagiz, Guryev-Astrakhan, Guryev-Karaton were built to supply water to the population of workers' settlements associated with oil production and maintenance of the railway with water intake from the river Ural. The share of groundwater in the balance of water consumption of the rural population of Atyrau region is 45-48%.

The layout of explored groundwater deposits is shown in Fig. 1.1.

For the Mangystau region, the main sources of drinking water supply are groundwater and an energy plant for seawater desalination. A significant amount of surface water is supplied to water consumers through many kilometers of water conduits. The prospective need of settlements for drinking water can be partially covered by the predicted resources of fresh groundwater in sandy massifs, as well as by desalination of brackish waters of Cretaceous deposits.

Groundwater is contained in deposits of the Quaternary, Neogene, Cretaceous, Jurassic and Paleozoic ages. The groundwater horizon in the described territory is underlain everywhere by a thick layer of clays of the Quaternary age, which is a regional aquiclude. It is believed that there is no significant overflow through the aquiclude. Therefore, the description of the aquifers and complexes lying below it is not given her [31].

Ground waters are confined to fine- and fine-grained, sometimes clayey sands of Quaternary deposits with interbeds of clays that are not consistent along strike. The total thickness of water-bearing deposits ranges from 2-10 to 15 m (Fig. 1.2).

Filtration properties of water-bearing rocks are low. Filtration coefficients are mainly in the range from 0,1-0,2 to 3-5 m/day. The depth of groundwater in a significant part of the coastal zone ranges from 1-3 m, increasing to 5-7 m in elevated areas of the described territory. Groundwater mineralization is high (from 10 to 300 g/l); the chemical composition is often sodium chloride.

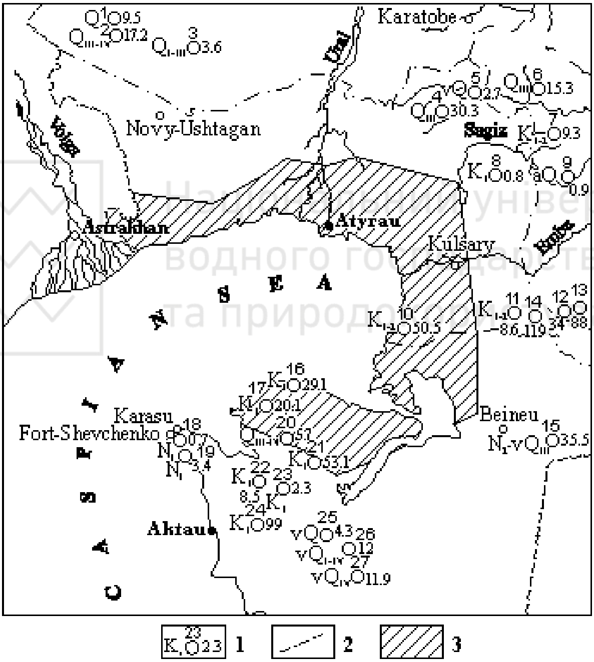

Fig. 1.1. Scheme of location of groundwater deposits: *1* - deposits with approved groundwater reserves in the sum of categories A+B+C_1+C_2 (thousand m^3/day); geological age index of water-bearing rocks and field number (*1* - Urda; *2* - Aimekenskoe; *3* - Iskrovskoe; *4* - Taisoiganskoe; *5* - Miyalinskoe; *6* - Uilskoe; *7* - Keregen-Sagizskoe, *8* - Eibetinsky, *9* - Oryskazgan, *10* - Tengiz, *11* - Balinsky; *12* - Myngyr; *13* - Mataykum; *14* - Zhanasusnoe; *15* - Samskoye; 16 - Aksyn-Kalamkassky site; 17 - Aktumsyk-Karazhanbasky section; 18 - Ketykskoye; 19 - Saubet; 20 - Kyzylkum; *21* - North Aktau; 22 - Ulanak; *23* - Akmysh; 24 - Kuyulus; *25* - Baskuduk; *26* - Sauskan; 27 - Tyuesu); *2* - conditional external border of the coastal zone of the Caspian Sea in the Caspian lowland; 3 - study area

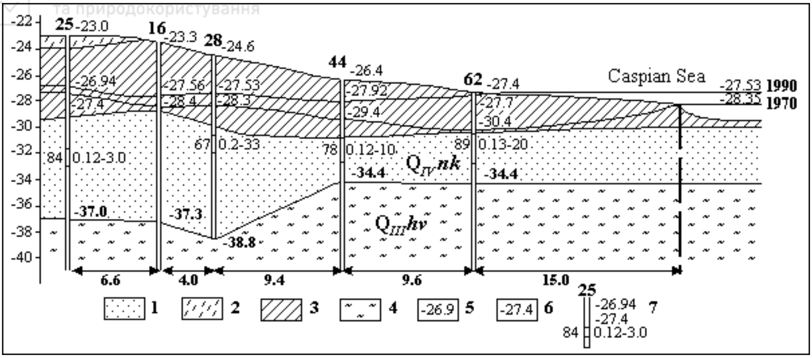

Fig. 1.2. Hydrogeological section along the line I-I: *1* - sands; *2* - sandy loam; *3* - loams; *4* - clays; *5* – groundwater level for 1970; *6* - groundwater level for 1990; *7* - well. Numbers: at the top - her number; on the left - mineralization, g/l; on the right - well flow rate, l/s and water level decrease, m; the numbers near the arrow are the absolute marks of the groundwater level

Groundwater has a single hydraulic surface with a slope mainly towards the Caspian Sea and numerous sor depressions into which groundwater is discharged. In low water, it is also carried out in the riverbeds. Groundwater is fed as a result of precipitation infiltration, water inflow from the Caspian Sea in certain sections of its coastline, as well as the loss of river flow in the flood.

1.3.2. Hydrogeological conditions of the Samskoye field

Conditions for the formation of groundwater, water abundance, degree of mineralization are determined by the features of the geological structure of the area, relief and climate.

The following aquifers are distinguished in the described area:

1. Aquifer of modern deposits (Q_{IV}).

2. Aquifer of Upper Pliocene-Upper Quaternary deposits ($N_2^3 + Q_{III}$).

3. Aquifer of the Upper Miocene deposits of the Sarmatian stage ($N_1^3 + S$).

Separately, the distribution contours of permeable, but practically waterless Upper Pliocene-Upper Quaternary deposits are distinguished. The distribution of groundwater, their mineralization, and chemical composition are shown on a schematic hydrogeological map at a scale of 1:100,000.

Recent sediment aquifer (Q_{IV})

The described aquifer is confined to the deposits of sors, which have spread along the outskirts of the Sam sandy massif. The largest of them are Sam, Samoldyn, and others. Water-bearing rocks are sands, sandy loams, and silts. The thickness of the described deposits reaches 10 m (sor Sam). In the northern direction, due to the uplift of the bed of underlying rocks, the thickness of the sor deposits decreases and, consequently, the thickness of the flooded stratum also decreases. The depth of the water level on the sors usually does not exceed 0,5 m, sometimes reaches 3 m. The aquifer is fed mainly due to precipitation and water influx from other aquifers, in particular, Upper Pliocene-Upper Quaternary deposits.

According to the chemical composition, the waters in the sor deposits are chloride-sodium and sulfate-chloride-sodium.

Upper Pliocene-Upper Quaternary aquifer ($N_2^3 + Q_{III}$)

The described aquifer is confined to the sand massif Sam. Water-bearing rocks are fine-grained sands, less often fine-grained, quartz-feldspar.

Groundwater, depending on the hypsometric position, occurs at various depths. The minimum depth of groundwater penetration corresponds to the zone from the unloading, the maximum depth - in the bed of dune sand development. The groundwater level varies between 1,35-29,0 m. The thickness of the aquifer varies from 2,2 to 26,5 m.

The aquifer of the Upper Pliocene-Upper Quaternary deposits is underlain by sandy loams, loams of the same age, as well as clays of the Lower Sarmatian stage. In some places, sands lie directly on the calcareous strata of the Lower Sarmatian.

The flow rates of wells, according to the data of numerous pumpings, vary within 0,35-6 l/s, with depressions of 2,3-4,5 m, respectively. The aquifer contains very variegated waters in terms of mineralization and chemical composition. Over the entire area of the massif, except for the central part of the sands, a change in the hydrochemical composition of groundwater is observed vertically from top to bottom. This pattern is especially pronounced in the marginal parts. The type of water in the fresh zone of the sandy massif is predominantly sulfate-chloride, sulfate-hydrocarbonate and hydrocarbonate-sulfate-chloride, less often hydrocarbonate. In the area of distribution of slightly brackish and saline waters, chloride-sulphate waters predominate; in the discharge zone, where the water level is closer to the surface, the mineralization reaches 34,7 g/l. The discharged waters create a backwater for the waters moving from the central parts of the massif to its outskirts, which creates a stagnant regime and an increase in the mineralization of groundwater. The aquifer is discharged into sors, which are located in the peripheral parts of the Upper Pliocene-Upper Quaternary deposits. For all lenses of the Sam sandy massif, the total slope of groundwater varies within 0,0007-0,0050.

The feeding area of the aquifer coincides with the area of distribution of the sandy massif. The main source of nutrition is atmospheric precipitation.

The described aquifer is currently used by the local population, both for drinking and for watering livestock. In the area of the village of Sam-2 for water supply to the compressor station, the Central Asia-Center gas pipeline and the Beyneu station.

Upper Miocene aquifer of the Sarmatian stage ($N_1^3 + S$)

In the study area, the aquifer of the Sarmatian stage is distributed along the outskirts of the Sam sandy massif. Water-bearing rocks are various limestones with a general slope to the axis of the North Ustyurt trough. The conditions of their occurrence, associated with structural features, determine both the thickness of the deposits themselves and the thickness of the flooded part, as well as the depth of the level. In areas of uplifts, the thickness of the deposits decreases, respectively, the thickness of the watered part of the section decreases and the depth of the groundwater level increases. In the zone of troughs, the thickness of precipitation and their water-containing part increase, and the groundwater table approaches the day surface. This is especially clearly observed in the region of the axial part of the North Ustyurt trough. In general, the thickness of the flooded part of the aquifer varies within 8-47,4 m.

The waters of the aquifer as a whole are free-flowing, however, in the area of the Samskoye depression, pressure and even weakly self-flowing waters have been discovered by wells. The creation of pressure is facilitated by the sharpness of absolute marks between the side parts of the depression, which are the feeding area, and its lowest part, as well as the presence of poorly permeable rocks in the roof of the complex.

The productivity of workings that reveal groundwater varies quite widely. In general, the flow rate fluctuates within the range of 0,55-8 l/sec with water level drops of 60-10 m, respectively. The mineralization of groundwater is very diverse, and the Sarmatian aquifer is also distinguished by a distinct vertical zonality. Slightly brackish waters with a salinity of 1-3 g/l are distributed in the crests of uplifts, which are partial feeding areas, from which groundwater moves along the slope of the layers towards depressions, to areas of discharge. In general, the total mineralization of groundwater ranges from 2-10 g/l. According to the ionic composition, the waters are predominantly sulfate and sulfate-chloride-sodium.

The feeding area of the aquifer coincides with the area of its distribution. Nutrition occurs due to atmospheric precipitation, partly due to infiltration of groundwater from the Upper Pliocene-Upper Quaternary deposits. Groundwater of the described aquifer is used for drinking and cattle watering.

1.3.3 Justification of drilling parameters of a typical well in the conditions of the Samskoye field

In [32] based on the study of the geological and technical conditions of the Samskoye field, it was substantiated that the use of a rotary drilling method with reverse circulation makes it possible to multiply the well flow rate; reduce their required number; improve the quality of produced water; drastically reduce the well completion time; significantly lengthen the time of operation of wells; provide high rate of penetration (ROP); reduce the cost per cubic meter of produced water. Below, in support of this proposal, mathematical algorithms are given that allow obtaining the necessary numerical characteristics.

In order for the mathematical apparatus to be focused on the specific geological and hydrogeological conditions of the considered groundwater deposit, a basic model of a water well was built, which must meet the requirements of economic, geological and technological factors. Taking into account the above requirements, the following typical model for drilling a water well was adopted (Table 1.1).

Table 1.1

Basic drilling parameters of a typical well

No	Parameter	Meaning
1	Drilling depth, N, m	200
2	Depth of the roof of the productive formation, N_R, m	170
3	Reservoir thickness, m	14
4	Filtration coefficient, K_F, m/day	6.3
5	Static formation head, H_S, m	100
6	Drilling diameter, D, mm	800
7	Drill string diameters: out./in., d_O/d_i, mm	146/136
8	The height of the mixture above the surface, h, m	10
9	Upward water flow rate, U_W, m/s	2.5
10	Rate of penetration, ROP, m/h	15
11	Mixer immersion depth, L, m	H 2

In a comparative assessment of drilling methods, the main role is played by the maximum possible drill bit diameters.

For rotary drilling with reverse circulation we accept the diameter value equal to 800 mm (Table 1.1).

For rotary drilling with direct circulation in the case of using the widespread installation 1BA-15V, the final diameter can be a diameter of 190 mm [33].

When percussive drilling with the UKS-22 rig, a well with a depth of 200 m requires a casing telescope consisting of six columns. With an initial diameter of 22 inches (600 mm), the final diameter is 12 inches (324 mm) [34].

The initial data given in lines 1-5 of Table 1.1 were taken as the basis for comparative calculations.

The general parameters used in the comparative analysis of the three drilling methods are given in Table. 1.2.

Table 1.2

General parameters used in the comparative analysis

No.	Parameter	Meaning
1	Maximum possible theoretical flow rate, Q_S, m^3/h	245
2	Depression required to achieve it, H_S, m	100
3	Permissible filtration rate, U_F, m/h	5,01

The results of comparative calculations are given in Table 1.3.

Table 1.3

Main indicators of drilling water wells

Parameter name	Rotary drilling	Percussion drilling	Reverse circulation drilling
Diameter of the receiving part *D*, m	0,190	0,324	0,800
Filter pipe diameter D_F, m	0,146	0,146	0,146
Sprinkling layer thickness δ, m	0,022	0,089	0,327
Required filter length at a flow rate of 245 m^3/h (Table 1.2), *L*, m	82	48	20
The highest production rate (at reservoir thickness m = 14 m), Q_{max}, m^3/h	41	71	176

According to the results of the work, rotary drilling with reverse circulation in the conditions of the Samskoye field has such advantages.

The maximum possible, taking into account the limited thickness of the aquifer, the flow rate of drilling with reverse circulation is 4,3 times higher than with rotary drilling with direct circulation and 2,5 times higher than with percussion-rope drilling.

If the reservoir thickness is not a limiting factor, then with the same flow rate, the indicated ratio will be valid for the required lengths of the receiving part. The larger the diameter, the smaller the required length, with a decrease in which the costs of both the equipment of the receiving part and its repair are reduced.

With the same diameter of the filter pipe, the maximum possible thickness of the gravel pack layer during reverse circulation drilling is 15 times greater than for conventional rotary drilling and 3,7 times greater than for cable percussion drilling.

Powerful gravel sprinkling provides the best quality of mechanical cleaning of the sampled water. The consequence of this is also the minimum time required for experimental pumping and the minimum length of the well sump. Such sprinkling also provides the maximum duration of overhaul operation.

It should be borne in mind that with rotary drilling of large diameter wells with reverse circulation, labor costs for the manufacture of a gravel pack are minimized. As a rule, gravel is filled manually through the wellhead, since the large area of the annular space eliminates the possibility of plugging and failure of the filled material to reach the receiving part.

1.4 Optimization of technological parameters of airlift operation when water wells drilling

Currently, a number of reverse circulation mechanisms have been developed during well drilling: airlift pumps, submersible piston pumps, devices that convert the direct flow of drilling fluid in the bottomhole zone into counterflow, etc. However, reasonable recommendations lack the choice of parameters for reverse circulation mechanisms and a large number of design drawbacks hinder the wide practical application of this drilling method [30].

A significant factor that reduces the efficiency of well drilling with reverse circulation is the uncertainty of airlift operating conditions. This is due to the fact that the depth of the well is constantly changing, the pressure in the annular space and in the drill string, the depth of the mixer immersion are changing, which means that the optimal parameters of the airlift are changing. Currently, there is no method for determining the parameters of airlift operation in changing drilling conditions.

On Fig. 1.3 shown how, in the process of drilling at a level close to the bottom of the well 1, equilibrium is established between the pressures outside and inside the drill string 3.

As a first approximation, the pressure outside the drill string can be taken as the hydrostatic pressure of the water column 13 of the corresponding height.

Inside the drill string there is a mixture 15 of water with air 14, which is supplied there through the mixer 4 from the compressor 6 through the air channel 7.

Let us consider the balance of external (with respect to the drill string) and internal pressures in more detail. This balance is expressed by the equation

$$P_0 = P_I, \tag{1.1}$$

where P_0 is the pressure outside the drill string; P_I is the pressure inside it.

The pressure outside the drill pipes consists of two components

$$P_0 = P_S + P_D, \tag{1.2}$$

where P_S is the hydrostatic pressure; P_D is the hydrodynamic pressure (pressure loss) of the downstream.

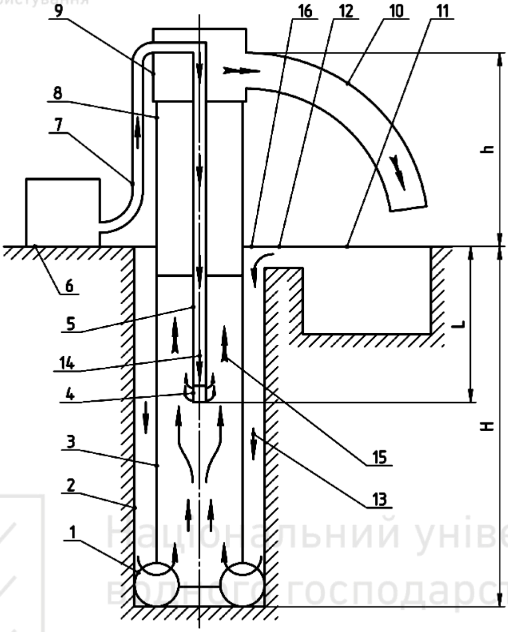

Fig. 1.3. To the algorithm of functioning of the airlift method during rotary drilling with reverse circulation: *1* - drill bit; *2* - borehole wall; *3* - drill string; *4* - mixer; *5* - air duct; 6 - compressor; *7* - hose; *8* - kelly; *9* – swivel: *10* - throwaway sleeve; *11* - sump; *12* - gutter; *13* - water; *14* - compressed air; *15* - mixture; *16* - the surface of the earth; H is the depth of the well; *L* - mixer loading; *h* - the highest height of the mixture (the highest height of the swivel)

Hydrostatic component of external pressure

$$P_S = \rho_W gL\,, \tag{1.3}$$

where ρ_W is the density of water (1000 kg/m^3); g - free fall acceleration (9,81 m/s^2), L - mixer load (distance from mixer to the surface).

Pressure losses inside the drill string also have static and dynamic components

$$P_I = P_{SI} + P_{DI}\,, \tag{1.4}$$

The hydrostatic component splits into two parts

$$P_{SI} = P_{S1} + P_{S2}\,. \tag{1.5}$$

where P_{S1} is the hydrostatic pressure of the mixture

$$P_{S1} = \rho_M g(L+h)\,, \tag{1.6}$$

where ρ_M is the average density of the mixture along the length $L+h$.

The flow moving along the internal channel of the drill string carries with it particles of destroyed rock, which increase the overall density of the upward flow, and hence the hydrostatic pressure. The second term in formula (1.4) takes into account the growth of hydrostatic pressure depending on the sludge content

$$P_{S2} = \Delta_F g(H+h), \tag{1.7}$$

where Δ_F is the increase in the density of the upward flow due to the sludge contained in it.

With regard to drilling with direct circulation, the required cuttings removal rate is determined based on the maximum allowable increase due to its content in the density of the upward flow. The required cuttings removal rate is

$$U_F = \frac{D^2(\rho_{F-}\rho_W)U_D}{(D^2 - d_O^2)\Delta_F}, \tag{1.8}$$

where ρ_F is rock density, U_D is ROP.

Transforming formula (1.8), we obtain the actual excess of the density of the upward flow due to the content of sludge in it at a known removal rate

$$\Delta_F = \frac{D^2(\rho_{F-}\rho_W)U_D}{(D^2 - d_O^2)U_W}, \tag{1.9}$$

Thus, we finally accept that for the sludge removal rate equal to the upward water flow rate U_W, the increase in the density of the upward flow is determined as

$$\Delta_F = \frac{D^2(\rho_F - \rho_W)U_D}{d_i^2 U_W}, \tag{1.10}$$

The hydrodynamic component of pressure inside the drill string includes three components

$$P_{DI} = P_{D1} + P_{D2} + P_{D3}, \tag{1.11}$$

The first component characterizes the pressure loss on the path of the upward flow of water from the bit to the mixer

$$P_{D1} = \rho_W \lambda_W (H-L)\frac{U_W^2}{2d_i}, \tag{1.12}$$

The coefficient of hydraulic resistance λ_W, as in the above case formula (1.8), is determined using the Reynolds criterion.

When water moves inside drill pipes, the Reynolds criterion is determined by the formula

$$R_{Ei} = \frac{\rho_W U_W d_i}{\nu}, \tag{1.13}$$

For the drilling conditions of a typical well, the rate U_W of water rise along the drill string from the bottom to the mixer is assumed to be 2,5 m/s. Given that the water density ρ_W is 1000 kg/m^3, its dynamic viscosity γ=0,0001 Pa s, and the inner diameter of the selected drill pipes is d=136 mm, the Reynolds criterion determined by formula (1,13) is $3{,}4 \cdot 10^6$. This is higher than 10^5 and is therefore indicative of a turbulent regime [35]. In this case, in formula (1.12), the coefficient of hydraulic resistance to the movement of water along a circular channel is defined as

$$\lambda_W = \frac{0.0121}{d^{0.226}}. \tag{1.14}$$

The second component in the formula (1.11) P_{D2} is the pressure loss due to the increase in density due to the content of sludge in the upstream

$$P_{D2} = \Delta_F \lambda_W (H + h) \frac{U_W^2}{2d_i}, \tag{1.15}$$

Since the sludge particles are located in the water flow, formula (1.15) uses the same values of the hydraulic resistance coefficient λ_W and flow rate U_W as in formula (1.12) directly related to this flow.

The third component in the formula (1.11) P_{D3} is the pressure loss during the movement of the mixture

$$P_{D3} = \rho_M \lambda_M (L + h) \frac{U_M^2}{2d_i}, \tag{1.16}$$

where L is the distance from the surface to the mixer (the depth of its loading); h is the maximum lifting height of the swivel above the earth's surface; U_M is the average rate of the mixture lifting at the specified interval L+h, λ_M is the average value of the coefficient of hydraulic resistance during the movement of the mixture.

With the height of the lift and the decrease in hydrostatic pressure, the air bubbles coming from the mixer into the water flow become larger and larger. For this reason, the volume of the mixture of water and air increases, which means (with a constant bore section of the drill string) its rate, also increases. From the fact that, as shown above, water that does not yet contain air moves in a turbulent regime, it follows that this regime can be adopted all the more for the movement of a mixture whose rate is higher. Therefore, $\lambda_M = \lambda_W$.

The pressure balance equation (1.7) for the drilling fluid circulation created by the airlift method, taking into account all the above components, takes the form

$$P_S + P_D = P_{S1} + P_{S2} + P_{D1} + P_{D2} + P_{D3}\,. \qquad (1.17)$$

From equation (1.17) it is possible to determine its average, effective density. We write this equation as follows

$$P_{S1} + P_{D3} = P_S + P_D - P_{S2} - P_{D1} - P_{D2}\,, \qquad (1.18)$$

Let us write out the content of the two terms on the left side of equation (1.18)

$$\rho_M g(L+h) + \rho_M \lambda_M (L+h)\frac{U_M^2}{2d_i} = P_S + P_D - P_{S2} - P_{D1} - P_{D2}\,. \qquad (1.19)$$

Or, bracketing the common terms

$$\rho_M (L+h)\left(g + \lambda_M \frac{U_M^2}{2d_i}\right) = P_S + P_D - P_{S2} - P_{D1} - P_{D2}\,. \qquad (1.20)$$

Where do we get the average density of the mixture

$$\rho_M = \left(P_S + P_D - P_{S2} - P_{D1} - P_{D2}\right) \Big/ \left((L+h)\left(g + \lambda_M \frac{U_M^2}{2d_i}\right)\right). \qquad (1.21)$$

Having determined ρ_M, we find from it the average rate of rise of the mixture. To do this, we use the mass flow equation

$$Q_W \rho_W + Q_A \rho_A = (Q_W + Q_A)\rho_M\,, \qquad (1.22)$$

where Q_W and Q_A are the volume flow of water and the average volume flow of air, ρ_W and ρ_A are the corresponding densities; ρ_M is the density of the mixture of water and air.

Transforming formula (1.22), we obtain the average volumetric air flow

$$Q_A = \frac{Q_W (\rho_W - \rho_M)}{\rho_M - \rho_A}\,, \qquad (1.23)$$

Since the density of air (even compressed air) is negligible compared to the density of water, the air density can be neglected and then the average volumetric air flow will be

$$Q_A = \frac{Q_W(\rho_W - \rho_M)}{\rho_M}, \tag{1.24}$$

Average mixture consumption

$$Q_M = Q_W + Q_A, \tag{1.25}$$

Substituting in this formula instead of Q_A its value obtained from formula (1.24), we obtain

$$Q_M = Q_W \frac{\rho_W}{\rho_M}, \tag{1.26}$$

Where is the average rate of the mixture

$$U_M = \frac{Q_M}{F_i}, \tag{1.27}$$

where F_i is the bore area of the drill string.

Formula (1.21) already involves the average flow rate of the mixture U_M, which has not yet been determined. This problem is solved by the method of successive approximations used in computational mathematics. Specifically, in relation to this case, this method is implemented as follows.

In formula (1.21), as an unknown value of U_M, the closest possible value (based on general considerations) is substituted. For example, it is advisable to use the value of the water flow rate

$$U_M = U_W, \tag{1.28}$$

The value of ρ_M thus obtained by formula (1.21) is then substituted into formulas (1.24) and (1.26), and then a new value of U_M is obtained by formula (1.27). This new value is again substituted into formula (1.21) and the calculation procedure according to formulas (1.24), (1.26) and (1.27) will be repeated, and the error in finding the value of U_M will decrease again. With each repetition of the described procedure, the error will decrease more and more.

The described procedure is repeated until the value U_M found by formula (1.27) differs in absolute value from the previous value found by the same formula, less than by a predetermined negligible value δ. The condition is set

$$U_M(j) - U_M(j-1) < \delta, \tag{1.29}$$

where j is the serial number of the above repeated procedures.

In the direction of movement of the drilling fluid in the direction from the bottom up with a decrease in height, the hydrostatic pressure decreases all the time. For this reason, the size of the air bubbles released from the mixer increases accordingly, which, in turn, causes an increase in the volume of the water-air mixture and a decrease in its density. With an increase in the volume of the mixture and simultaneously with a decrease in its density, its flow rate increases.

By dividing the well according to its depth into conditional intervals of the same length, we can calculate the change in density

$$\rho_{M\Delta}(i) = \rho_M(i) \cdot i - \rho_M(i-1) \cdot (i-1), \tag{1.30}$$

In this formula, $\rho_{M\Delta}(i)$ is the average density on some interval number i; $\rho_M(i)$ - effective density from the mouth to the lower boundary of i - that interval, $\rho_M(i\text{-}1)$ - effective density from the mouth to the lower boundary of the previous interval. Index i is not only the number of the interval, but also the number of conditional intervals included in the distance from the wellhead to the depth of the well, i.e. to the lower limit of the considered conditional interval.

An important result of the above algorithms is the ability to set the required air supply by the compressor. Since the volume of air is inversely proportional to the pressure that acts on it, the compressor flow is usually referred to as atmospheric pressure. The compressor flow in relation to the airlift reverse circulation method can be found by the average air flow for the first (from surface) interval.

$$Q_{ABAR} = \frac{Q_{A\Delta 1}(\rho_{M\Delta 1} g (0.5 h_1) + 10^5)}{10^5}, \tag{1.31}$$

In this formula, on the left is the air flow rate, providing a given rate of rise of the drilling fluid, at atmospheric pressure. On the right in the numerator before the brackets is the air flow in the first interval, and further in brackets is the hydrostatic pressure in this interval (related to its middle) including the density of the mixture, the acceleration of gravity and the height of the interval.

1.5. Modeling of drilling water supply wells with airlift reverse circulation

Based on the theoretical provisions outlined above, a computer model of the airlift method of reverse circulation of the drilling fluid has been created [36].

The parameters of the drilling process are fed to the model input, and in addition, the technological parameters of the model itself.

In the calculation block, the entered parameters are transformed into the desired output values. Initially, the values are calculated, which do not change in the future (outside the cyclical value). This is followed by two nested program cycles.

The task of the external cycle is to establish the dependence of the output values on this investigated parameter A of the drilling well. This parameter is changed according to the formula

$$A(i) = A(0) + dA \cdot i, \quad (1.32)$$

where i is the cycle number (step number); $A(0)$ is initial (i=0) parameter value A; dA is a step of its change. The required values of these magnitudes are fed to the model input along with the number of steps n. When the value of the mixture velocity U_M is required during the external cycle, the transition to the internal cycle occurs.

In the internal cycle, the flow rate of the water-air mixture U_M, as well as the associated output parameters ρ_M, Q_A,Q_M, is determined by iterations. An arbitrary value is supplied to the input $U_M(0)$, its acceptable mistake δ, and the largest number of m passes. The block of the inner loop contains a condition under which the loop is terminated and its results are transmitted to the outer loop, which continues. Thus, the external cycle, with each of its passage, begins with the calculation of uncorrectable (unrelated to U_M) quantities, and then it is interrupted by an internal loop and, after its completion, continues printing the results, including U_M-based output parameters.

All calculations on the model were carried out with magnitudes whose values were set in the SI system of units. However, when demonstrated in tables and graphs, extra-system values were used for the convenience of placing and perceiving numerical values.

The considered technique was used to study the drilling of water intake wells at the Samskoye field. Drilling large-diameter water intake wells with reverse circulation will be very effective here. For calculations on the model, typical drilling conditions at the field are accepted, presented in Table 1.4. Below, using the developed model, the dependences of the output parameters on the drilling parameters are constructed.

Some blocks of the model contain data common to all dependencies. These are the parameters of a typical well according to Table 1.4.

Table 1.4

Drilling parameters of a typical well

Name of the parameter	Unit	Value
Drilling depth, H	m	200
Mixer loading depth, L	m	H·2
Drilling diameter, D	mm	800
Drilling column diameters: external/internal, d_0/d_i	mm	146/136
The height of lifting the mixture above the surface, h	m	10
The speed of the rising water flow, U_W	m/s	2,5
Drilling speed, U_D	m/h	15
Water density, ρ_W	kg/m^3	1000
Dynamic viscosity of water	Pa·s	0,0001
Rock density, ρ_F	kg/m^3	2600

The results of off-cycle calculations are also common.

In further calculations, the values indicated in Tables 1.4 and 1.5 are used only if they are necessary to establish this considered dependence. The remaining values, being entered (Table 1.4), or calculated (Table 1.5), may in this particular case remain unused.

The values on which the dependence is established are not taken from Tables 1.4 and 1.5, but are specified separately, in accordance with the (1.32).

Solving research problems in conditions of the Samskoye field.

In Table 1.4, a well with a depth of 200 m is proposed as a typical well. However, when determining the dependence of the output parameters on the depth, in order to conduct an analysis for the extreme case, the considered depth of the well is extended to 300 m.

In Fig. 1.4 it can be seen how with increasing depth and hydrostatic pressure, the volumetric airflow rate Q_A drops sharply. The flow rates of the air-water mixture Q_M exceed Q_A by 2,178 m^3/min.

This is a given (Table 1.5) water flow, which, unlike airflow, is constant and does not depend on depth. The rate of increase in density ρ_M is the same as the rate of decrease in its consumption Q_M.

Table 1.5

Off-cycle computing

Name of the parameter	Unit	Value
Through section of the drill pipe, F_i	m^2	0,0145
Drilling fluid consumption, Q_W	m^3/s	0,0363
The Reynolds Criterion, R_E		$3{,}4 \cdot 10^6$
Coefficient of hydraulic resistances, λ_W		0.019
Hydrostatic downhole pressure, P_{SO}	atm	19,620
Density increase due to sludge, $_F$	kg/m^3	92
Hydrostatic component of sludge pressure, P_{Si2}	atm	1,901
Its hydrodynamic component, P_{Di2}	atm	0,085

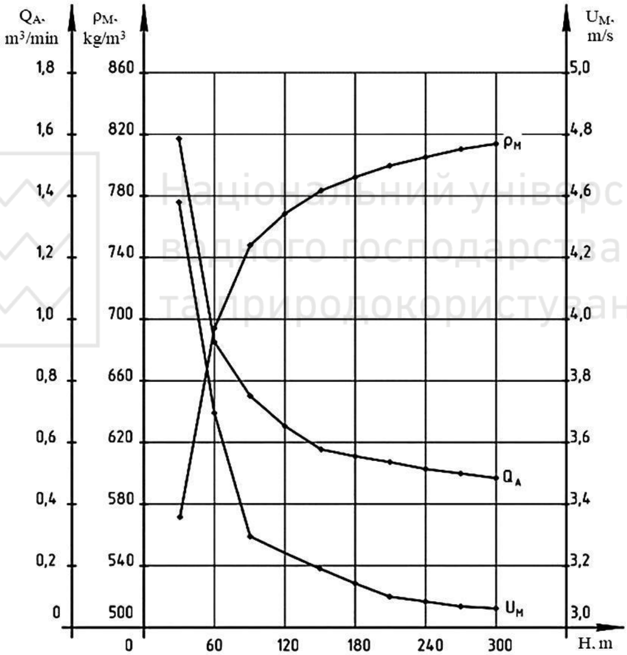

Fig. 1.4. The dependence of the average effective values of the mixture density ρ_M, its rate of rise U_M and air flow Q_A on the depth H

In addition to the U_M velocities, their differences U are given here compared to the previous passage. It can be seen how with each passage these differences fall and for all depths except 30 m, they become less than δ=0,005 already at the fourth iteration.

In Fig. 1.5, both ρ_M and $\rho_{M\Delta}$ (mean-effective and interval density values) increase with depth, but interval values increase more intensively. The fact is that, unlike the average effective values, the low densities of the upper intervals do not affect them.

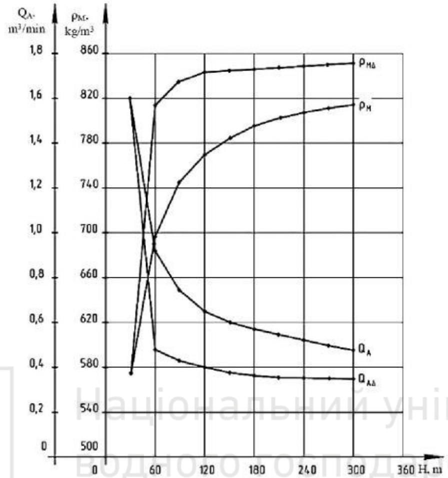

Fig. 1.5. Comparison of the average effective ρ_M and Q_A and the interval values of the density of the mixture of ρ_M and air flow Q_A

According to Table 1.4, the most effective position of the mixer corresponds to the full depth of the well minus 2 m - in order to avoid turning the compressed air into the annular space. This requirement was observed above when considering the dependence on the depth of the well and below for all other dependencies except for the one considered in this. In some cases a higher location of the mixer provides an increase in the possible well depth [34].

The values of P_{SI2}, P_{DI2} and P_{DI1} are subtracted from the hydrostatic pressure P_{S0} of water in the annulus at the mixer level.

The analysis of Fig. 1.6 shows that with a decrease in the depth of the mixer descent, the density of the mixture decreases in the form of a curve gaining steepness, and the air consumption increases in a similar way.

The results of processing input data on a computer model are presented in Fig. 1.7. The increase in the density of the ascending water flow F is proportional to the drilling speed U_D, according to which U_D multiplies as if by a constant coefficient.

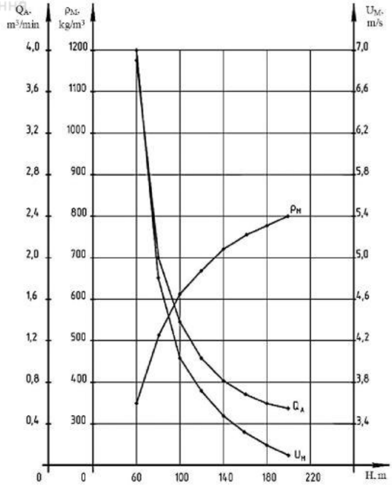

Fig. 1.6. The dependence of the average effective values of the density of the water-air mixture ρ_M, its rate of rise U_M and airflow Q_A on the depth of the mixer loading

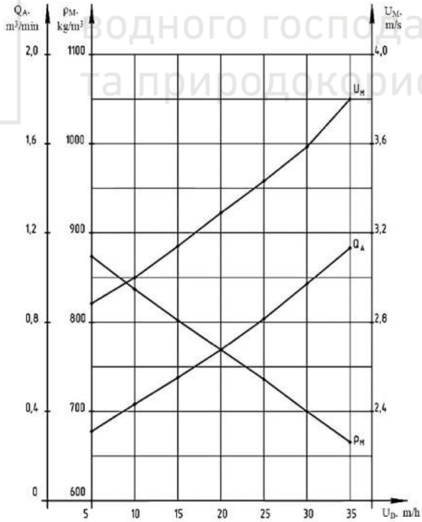

Fig. 1.7. The dependence of the average effective values of the density of the water-air mixture ρ_M, the rate of its rise U_M and airflow Q_A on the rate of deepening U_D

The increase in the density of the ascending water flow Δ_F is proportional to the drilling speed U_D, respectively, the pressures P_{SI2} and P_{dI2} caused by the presence of sludge increase. Their growth causes a drop in the density of the ρ_M mixture (Fig. 1.7) by increasing the air content in it Q_A, which has a nonlinear accelerating character.

1.6. Improvement of technology for drilling large diameter wells with reverse circulation

The disadvantages of the airlift method are reduced to the need for a significant complication of the design of the drill string, which must not only ensure the removal of drill cuttings to the surface, but also the supply of compressed air to the mixer (while the reverse suction method allows the use of a conventional commercially available drill string).

The most common type of drill string is that the drill pipes are connected by welded flanges having three through holes. The hole located in the center of the flange has a diameter equal to the inner diameter of the drill pipes. Two other, smaller holes are located symmetrically with respect to the central hole. They correspond to the inner diameter of the compressed air supply pipes located outside the drill pipes. Flanges with the help of bolts and sealing gaskets connect such triple pipes into a single column. The pins are designed for easy alignment of the connected flanges, as well as for torque transmission.

A disadvantage of flanged drill strings is that such drill strings and their connections are very different from standard commercially available drill pipes and their connections. In practice, serial pipes have to be recut, removing the threaded ends and prefabricated flanges are welded onto the ends, ensuring their strict parallelism (its absence violates the tightness of the column).

The connection of two pipes takes an average of 30 minute [37]. The connection process takes up a large part of the working time balance in well construction. However, flanged connections are the most common.

There are also a number of other ways to supply compressed air to the mixer. In particular, instead of flanges, pipes can be connected using special weld-on joints with conical threads. The diameter of the joint is sharply increased taking into account the attached air pipes, the same type as with flanged connections.

Such joints reduce the connection time by about half, but they are complex and increase the cost of the drill string significantly more than flange connections. The practice of using such connections has shown that they do not provide reliable sealing of the drill string [38]. In addition, tool joints have not of the advantages of a flange connection, in terms of the possibility of both right and left rotation of the drill string.

Some firms use concentric twin drill strings. An upward flow of pulp is created in the inner column, and air enters through the annulus between the pipes. Columns can have both flange and joint connections. The described method increases the weight and cost of the drill string and, ceteris paribus, is characterized by a reduced flow area of the pulp-lifting part.

Sometimes the method of separate descent of the drill and air strings is used. Air string runs inside the previously run drill string. During drilling, it does not rotate and has its own swivel located above the swivel of the main string. The process of building up and tripping such a combined drill string is sharply complicated and takes a lot of time. In addition, the inner column hinders the passage of large slurry particles.

Summing up, we note that both of the above methods for creating reverse circulation are characterized by the following features [39].

The most important advantages:

- For the reverse suction method - the uses of commercially available drill pipes and connections;

- For the airlift method – the absence of physical restrictions in the intensification of circulation and increasing the depth of wells.

Main disadvantages:

- For the reverse suction method -the use of a vacuum created by a centrifugal pump, which is limited by atmospheric pressure, as a drive for the circulation system.

- For the airlift method - complication of the design of the drill string due to the addition of the cuttings removal function to the function of air supply to the airlift mixer.

The main disadvantage of reverse circulation is due to fundamental physical laws, and therefore it is not possible to eliminate it.

The main disadvantage of the airlift method is associated with the design of the drill string and can in principle be eliminated. However, existing solutions to this problem are cumbersome and require a lot of time and money.

The elimination of the main disadvantage of the airlift method is the purpose of the proposed device [40].

The essence of the device is that instead of special drill pipes with special connections, commercially available drill pipes with commercially available connections are used.

Air is supplied from the compressor to the mixer through a hose wound on a drawworks included in the drilling rig. Through a swivel, a hose with a mixer at the end is wound into the drill string to the required depth.

The scheme of the device is shown in Fig. 1.8 [41].

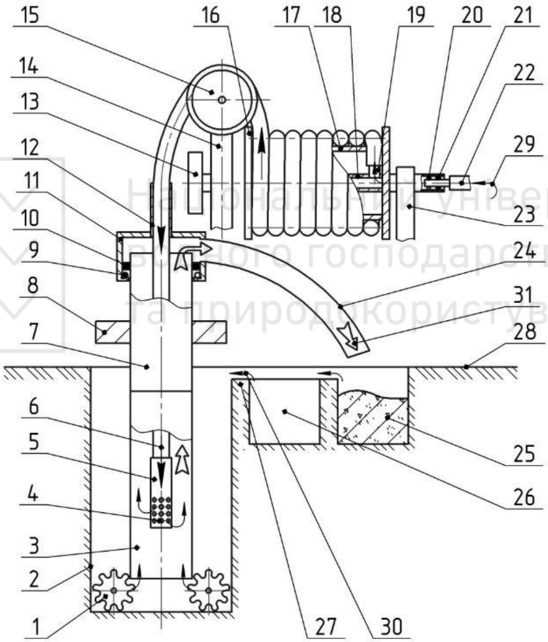

Fig. 1.8. An improved version of the device of the circulation system for drilling wells with reverse circulation using an airlift: *1* – drill bit; *2* – borehole wall; *3* – drill string; *4* – mixer; *5* – weighting pipe; *6,22* – hose; *7* – kelly; *8* – rotor; *9, 20* – bearing; *10, 21* – seal; *11* – swivel body; *12* – guide pipe; *13* – drive gear; *14, 23* – drawworks shaft support; *15* – pulley; *16* – drawworks; *17* – drum; *18* – shaft; *19* – fitting; *24* – throwaway sleeve; *25* – sump; *26* – capacity of the purified fluid; *27* – gutter; *28* – day surface; *29* – compressed air from the compressor; *30* – downward flow of fluid; *31* – ascending flow of water-air pulp

The device works as follows. In the process of drilling, compressed air *29* from the compressor through a hose *22* with a fitting through the stuffing box *21*, and bearing *20*, enters the hollow shaft *18* of the drawworks *16*. From the shaft through the fitting 19, the air enters the initial coil of the hose *6* wound on the drum *17*. C of the drum through the pulley 15, the hose enters the guide pipe *12* and through it through the central hole in the cover of the swivel *11* – into the kelly *7* and further – along the central axis of the well – into the drill string *3*. At the end of the hose, a weight pipe *5* is fixed, with a mixer *4*.

Since the hydrostatic pressure of the slurry column *31* (a mixture of drilling fluid, air and drill cuttings) is less than the hydrostatic pressure of the drilling fluid column in the space between the drill pipes and the well, the drilling fluid, together with the destroyed rock, rushes up to the mixer and then, together with air, to the upper end leading pipe. Here in the body of the swivel there is a hole connecting the swivel with the hose 24, through which the pulp merges into the sump (sludge collector *25*), where the sludge settles, and the purified fluid flows through the chute 27, and, overflowing the container *26*, enters the annular space of the well and then returns downhole to the bit working there. This completes the circulation cycle.

As the well deepens, the brake of the drawworks 16 is periodically released (the brake is not shown in the figure) and the weight pipe *5* causes the hose to be reeled to the appropriate length (or the drum starts to rotate in the direction of the descent using the drive).

Before connecting the drill string or before tripping operations, the hose is removed from the drill string with the help of a drawworks *16* until the weight pipe *5* with the mixer *4* is hidden inside the kelly *7*. When performing operations for connecting drill pipes, the hose is held by the brake of the drawworks in the leading pipe taken away from the mouth. After completion of the operation of making up the drill pipes and connecting the kelly to the drill string, the brake is released, and the pipe 5 with the mixer and the hose are lowered into the well to the required position.

1.7. Conclusions

1. An analysis of the geological and hydrogeological conditions of the Samskoye groundwater deposit was carried out. Aquifers are

composed mainly of sands with a filtration coefficient of 5-7 m/day, and the thickness of the layers varies widely, averaging 10-20 m, and the depth reaches 200 m.

2. Based on the literature data, the effectiveness of the main methods of drilling water wells was analyzed in relation to the conditions of the Samskoye field. The drilling of water wells carried out, as a rule, by a rotary method with direct circulation or by a percussion method.

The total water withdrawal from all wells at the Samskoye field does not exceed 18% of the proven reserves. It is obvious that the methods of construction of water wells used in this field do not allow for the water withdrawal necessary to meet the needs of the region in drinking and household water supply.

3. As a result of a comparative analysis of existing advanced technologies for drilling wells with reverse circulation of drilling fluid, it was found that for the conditions of the Samskoye field, the most effective method is rotary drilling of water wells using reverse circulation created by the airlift method. Its application will ensure a sharp increase in the flow rate and quality of produced water, while reducing the time and cost of well construction. It has been established that a significant drawback of the chosen drilling method is the need to use special drill string connections, which leads to high time spent on round trips and drill string extensions.

4. As a result of the analysis of scientific, technical and patent sources, it was found that a significant factor that reduces the efficiency of well drilling with reverse circulation is the uncertainty of the airlift operating conditions. This is due to the fact that the depth of the well is constantly changing; the pressures in the annular space and in the drill string are changing too, which means that the optimal parameters of the airlift are changing.

5. Based on the analysis of the geological and geographical conditions for the construction of water wells in the Mangystau region, a typical model for drilling water well in the conditions of the Samskoye field was developed.

6. A mathematical algorithm has been developed for studying the airlift circulation method during rotary drilling with reverse circulation, based on the analysis of the pressure balance in the annulus and in the drill string that occurs during drilling. The pressure balance

takes into account both hydrostatic pressures and pressure losses for pumping water and water-air mixture.

On the basis of mathematical algorithms, computer models were created that made it possible to investigate the main dependences of the required values of the output parameters on the given conditions. Calculations were made in relation to a typical well, the individual parameters of which were varied to obtain the corresponding dependencies.

7. The main disadvantage of the airlift method is the need to abandon mass-produced drill pipes in favor of special multi-channel drill pipes and their connections. As a result, there is a significant increase in the time spent on connections in the processes of building up the drill string and tripping. There is also an increase in the cost of the drill strings themselves.

The disadvantages of the airlift method can be eliminated if the proposed new technology is introduced, for which a patent of the Republic of Kazakhstan has been received.

The essence of the invention consists in the refusal to use the drill string as a channel for supplying compressed air to the mixer. It retains only its traditional functions, and thus it becomes possible to use commercially available drill pipes with conventional connections.

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ENSURING ENVIRONMENTAL SUSTAINABILITY OF FOREST ECOSYSTEMS ON DISTURBED LANDS WITH UNAUTHORIZED AMBER MINING

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Summary

Human activity is connected with the use of natural resources and conditions. The result of the intensive use of certain types of resources is the formation of disturbed and degraded lands, the change of natural landscapes. Negative changes in the natural state of land resources, the formation of degraded lands occur both as a result of economic activity and as a result of the action of natural factors.

A number of measures are used to restore unproductive, degraded, technologically polluted and disturbed lands. The complex of organizational, economic, technical and biological measures is determined by the factors that cause the occurrence of violations and the subsequent type of land use. Restoration and improvement of the land cover is carried out through its reclamation. This article describes and reveals the essence of the reclamation of produced peat deposits by its afforestation[1].

Reclamation of disturbed lands is a complex of organizational, technical and biotechnological measures aimed at restoring the soil cover, improving the condition and productivity of disturbed lands [2].

Land disturbance occurs during the development of mineral deposits, geological exploration, research, construction and other works, as well as due to the harmful effects of water. At the same time, the soil cover is disturbed or destroyed, the hydrological regime changes, man-made relief is formed, etc. As a result of land reclamation, agricultural and forest lands, reservoirs for various purposes, recreational areas, and areas for development are created on disturbed lands.

Introduction

Reclamation of disturbed lands, the land area of which in Ukraine, according to State Committee on Land Resources (SCLR), is more than 160 thousand hectares, restoration of their soil cover and return to the sphere of economic sectors, is one of the most important problems of nature management.

The goal of reclamation is not only the partial transformation of disturbed natural territorial complexes, but also the creation of more productive and rationally organized anthropogenic landscapes in their place. In connection with the increase in disturbed lands, reclamation has become an integral part of the protection and reproduction of land resources. Projects for reclamation of disturbed lands are developed on the basis of the task and design of technical conditions [2].

In the reclamation project, the technical and economic feasibility of reclamation is established, the type of further targeted use of the reclaimed land is substantiated, the scope of work of the technical and biological stages of reclamation is determined, and the most rational complexes of machines and equipment are selected.

Design organizations of the SCLR system, the Ministry of Agrarian Policy, the Ministry of Ecology and Natural Resources, and the Ministry of Education and Science of Ukraine are involved in the design of biological reclamation on contractual terms.

The development of individual sections of the project (extinguishing, development, lowering and reshaping of mine tericons followed by their landscaping) or landscaping projects without performing the work of the technical stage of reclamation is allowed to be carried out by divisions of production facilities with the involvement of specialized organizations on contractual terms or using the recommendations developed by them.

Materials of the technical project are transferred to the customer by the project organization (general designer) in four copies, and to the subcontracting project organization in five copies, except for objective estimates, the number of copies of which should be one more. In cases of execution of certain types of work by subcontracting organizations or land users, the project organization shall provide the customer with one additional copy of objective estimates for each subcontracting organization (land user). Working drawings are issued to the customer in four copies. The technical and working project is issued to the customer in the same number of copies as the working drawings.

Reclamation projects establish the economic efficiency of costs in the process of agricultural and fishery reclamation, which is determined by the time at which reclamation costs will pay off years

$$E_з = \frac{\mathrm{T} \cdot B}{E_p} \quad (1)$$

where T is the amount of costs for the technical stage of reclamation, UAH/ha;

B - the same for the biological stage, UAH/ha;

E_p - annual income from the sale of agricultural (fish) products from reclaimed (irrigated) area, UAH/ha.

The initial data for calculating the economic efficiency of reclamation is used from the following sources:

- costs for the technical and biological stages of reclamation - from the estimate to the project;

- a list of agricultural crops - from the structure of crop rotations in which the plot is expected to be used, or from the crop rotation, if they will be used outside the crop rotation; in the design of the reservoir, the species of fish that will be bred are established;

- costs for the production of a unit of production - from the materials of agricultural or fishing enterprises of the annual reports of farms located near mining enterprises;

- costs for processing and sales of products are estimated to be 7,2% of the total costs of products sold.

The comparative economic efficiency of biological reclamation can be calculated as at minimal costs

$$C_1+E_н K_р=\min \tag{2}$$

and for maximum profit

$$E_р-E_н K_р= \max \tag{3}$$

where C_1 - current costs for each option, UAH;

$K_р$ - capital costs for reclamation1 ha of land, including production losses associated with land disturbance, UAH;

$E_р$ - the total size of the average annual effect from reclamation1 ha lands, UAH;

$E_н$ - regulatory efficiency ratio of capital investments.

According to the State Forestry Agency of Ukraine, 3,5 thousand hectares of forest have already been damaged in the forests of the Rivne, Zhytomyr and Volyn regions due to unauthorized amber mining. This happens because illegal miners do not follow the mining technology, washing out the amber stone with motorized pumps, which leads to the destruction of underground water drainage channels. However, the reclamation of lands and forest plantations, which remain in a catastrophic state after the diggers, remains out of the attention of all participants in this industry [3].

Depending on the type of farming the reclaimed land will be used for (forestry or agriculture), the following types of work can be carried out. After the extraction of amber by hydraulic and mechanical methods, embankments and funnels are formed, first it is necessary to level the surface with the help of bulldozers and, if necessary, excavators. The next process of site reclamation consists in the fact that it is necessary to carry out the process of mixing milled peat with the surface layer. This operation can be performed with the help of tractors - tractors on a wheel drive with increased passability or on a crawler drive and cultivators or discs, which are used for disking land in agricultural works [3].

Reclamation of produced deposits and disturbed areas, as a result of unauthorized amber mining, through its afforestation is one of the world-recognized directions of their reclamation. The forestry direction of land reclamation is the creation of forest plantations of various types on disturbed lands. The requirements for land reclamation in the forestry direction should provide for the creation of plantations for operational purposes, and, if necessary, forests for protective, water-regulating, and recreational purposes.

To create conditions that prevent the development of erosive processes and the safe use of tillage, afforestation machines and plantation care machines, land surface planning works are carried out. They include works on the creation of forest plantations in unfavorable soil conditions that perform reclamation functions, selection of tree and shrub plants taking into account soil types, the nature of the hydrogeological regime and other environmental factors. The question of the organization of fire fighting measures must be considered.

When afforesting disturbed areas and produced deposits, it is advisable to follow the such recommendations [4].

- Because developed fields, after the extraction of minerals, are located on the lower parts of the terrain, their forestry use is possible only with high reliability of the drainage network.
- Forest growth conditions depend on the fertility and strength of the remaining layer of peat and the composition of the rocks of the mineral bed.
- Reclamation must be carried out in the first 2-3 years after the decommissioning of the areas, until the creation of a powerful grass cover and the natural restoration of the shrubbery (mainly verbolisis - thickets of willows). Overgrown areas require additional labor costs and funds for reclamation during their afforestation.
- Areas on which tree species have recovered well in the amount of at least 20,000 pieces/ha with their uniform located by area, are included in the forest fund without additional cultivation of crops.
- Natural regeneration of the forest.
- Soil preparation for afforestation depends on the category of the field according to the level of groundwater.

Natural regeneration of the forest on cultivated and disturbed agricultural and forest lands.

Natural regeneration of the forest depends mainly on the regime of groundwater, properties of peat, the presence of a source of insemination, etc. [5].

For the first 2-3 years, the developed areas are not overgrown with woody vegetation, only in some cases self-sowing willows and birches appear. Initially, they inhabit low-lying, waterlogged areas that are periodically flooded, and the slopes of the drainage network.

Then they spread throughout the massif. In areas that are flooded, self-sowing plants gradually differ in growth. Trees develop best on natural micro-elevations, low areas are overgrown with reeds, sedges, bulrushes, etc.

In the elevated areas, recovery is weaker due to the lack of moisture in the upper layers and the wind blowing the seeds to the lower areas. The species composition of self-regenerating crops is very limited: it is mainly downy birch, and aspen, pine, and spruce regenerate much worse. Aspen and spruce grow quite well in areas with groundwater level from - 0,2 to 0,6 m. Pine grows better in areas with a lower level of groundwater, that is, in elevated and medium areas [6].

A large number of self-sowing plants grow in areas with a deep layer of peat, because in the spring the peat swells up a lot, and with the onset of warm days it shrinks a lot.

In addition, areas with a significant layer of peat become overgrown with grass earlier and more intensively, which prevents the restoration of woody species. Therefore, produced deposits can self-restore, but the range of woody species will be quite limited, therefore, the main area of disturbed land should be subject to cultural afforestation.

Soil preparation

Processing soil has a decisive role in the productivity of forest plantations, as it determines the water-physical, air, agrochemical and microbiological properties of the soil. Types of processing include continuous processing (plowing), creation of micro-elevations and making furrows.

Continuous cultivation changes the layer in which the horizontal roots are located, which make up 90 % of the root system.

Creation of micro elevations in the form of shafts improves conditions on one part of the area due to deterioration (pits, furrows) on the other and enables crops to overcome the most unfavorable periods (flooding, waterlogging).

Conducting furrows worsens the agrochemical and water-physical properties in the areas and slightly improves them outside of them. It is used where the provision of moisture is crucial in the first years, as their bottom is moistened better than the slopes and ridges of the shafts.

The quality of any type of soil treatment depends on the type of treatment tool.

Soil processing in forestry production is carried out only when creating crops, then natural processes take place.

The choice of the method and terms of creation of cultures

The following ways of creating cultures are possible:

- the natural process of forest restoration as a result of self-sowing of seeds, but environmental conditions are not always favorable for the emergence of seedlings and their subsequent growth and development;
- sowing pine and spruce seeds 10-12 pcs. in the sowing place. The success rate of this method is low: 69-81% of the plants did not come off;
- the main method of reforestation is planting saplings. It is carried out manually or forestry machines. In low places where micro elevations are created, planting is carried out manually, since it is difficult to move equipment on the prepared soil and there is a high probability of significant damage to the shafts.

The success of forest crops strongly depends on the period of planting. Survival and preservation of plants planted in spring is much higher than in autumn.

The main reason for the loss of plants in low places is wetting and washing of plants (37-64%) and crushing (13-40%). Spruce is best stored here.

Autumn planting of medium and high fields is more successful, but also unsatisfactory in general. Pine seedlings are especially poorly preserved (41-75% loss).

Survival, conservation and success of cultivated tree species

The success of forest crops is evaluated by their survival after planting seedlings and by their growth rates. Their survival depends on the breed, the age of the planting material, the soil category, weather changes, susceptibility to the development of weeds, etc.

On medium and tall one-year-old pine saplings, this indicator varies from 87 to 100%, and decreases to 53-94% in two-year-olds. High survival rate (90-100%) of two- and three-year-old firs and 1-2-year-old birch, somewhat lower for aspen (48-79%).

On low fields survival of one-year seedlings pine trees is: on unprepared soil 89-95%, after plowing - 71-93%, on ridges of shafts 80-87%. Survival of two-year-olds does not exceed 37-86%. In spruce and birch, this indicator is much higher (97-100%), in black alder it decreases to 74-98%.

In all cases, survival on deep peat is significantly lower than on a mixture of peat and sand.

On areas prone to intensive overgrowth with weeds, use large saplings up to 0,4-0,6 m, which allows you to get rid of time-consuming and costly expenses.

In terms of growth indicators, warty and downy birches are the best in low fields.

Pine accelerates growth in height only from the second year, spruce from 4-5, and birch and alder, under favorable conditions, already from the year of planting.

Large pine and spruce saplings tend to get sick after 2-3 years and only then develop normally. Alder, spruce, aspen, poplar, oak suffer from freezing in depressions of middle fields.

Successful development of breeds that grow quickly and build up a significant mass of roots, which fasten the peat soil before the beginning of the autumn-winter season. These species include poplar or energy willow (Fig. 1).

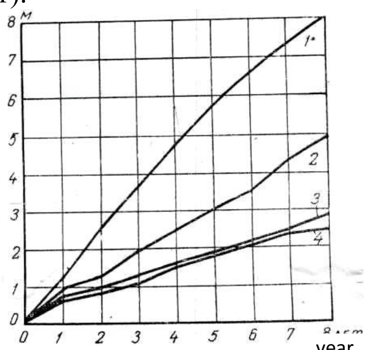

Fig. 1. Growth of crops on various produced peat deposits: *1* - cultured peat; *2* - produced edge; *3* - deeply peated areas, low fields; *4* - shallow bottom deposit

Having analyzed fig. 1. it can be concluded that only on cultivated (processed and fertilized) uncultivated outskirts, shallow areas with favorable aeration, these cultures form highly productive plantations.

Care of forest crops

The preservation and growth of crops strongly depends on the development of weeds and the application of mineral fertilizers.

Weeds and their growth dynamics differ significantly in different cultivated fields. The most intensive development of weeds onfertile deposits of low fields. These are hypericum, cypress, thistle, quinoa, common wormwood, etc., which reach a height of 60-80 cm, the degree of coverage is 70-100% and at the same time it is increasing 8-18t/ha of green mass, then grasses take root, which after 4-5 years form a solid sod.

Medium- and poorly decomposed peat is covered with mother-and-stepmother, marsh horsetail, occasionally reed. They develop weakly, so they are not a threat to the development of cultures.

There are mechanical and chemical methods of weed destruction. Among the first, loosening of the inter-rows with cultivators, weeding with hoes, mowing of weeds and their trampling by various means are used. The efficiency of the mechanical method is low.

The best results are observed with the use of chemical agents, among them triazine herbicides such as radocor, simazine and atrazine. When entering 20 kg of the active substance per hectare of soil, they thin out the grass by 80%. Their effectiveness depends on the terms of introduction. The most effective application is before the emergence of weeds.

Application of mineral fertilizers

Application of mineral fertilizers to accelerate forest growth is necessary due to the poverty of the substrate for phosphorus and potassium.

Application of only nitrogen, potassium and copper-containing fertilizers ($N_{60}Cu_{12}$ and $N_{60}K_{120}$) does not cause noticeable growth of weeds. Superphosphate ($N_{60}P_{90}$ and $P_{90}Cu_{12}$) and especially phosphorus-potassium fertilizers intensively provoke the growth of weeds, which reduces the squeezing of seedlings, protects them from frost and burns, that is, contributes to their preservation.

A significant acceleration of the growth of forest crops is observed with the introduction of phosphorus-potassium mixtures and various combinations of complete fertilizers, in which the potassium content exceeds the phosphorus content. Already in the first year, growth in height increases by 2-7 times. The best mixture is phosphorus-potassium fertilizers in the ratio $P_{90}K_{120}$ of the active substance. Fertilizers must be applied to pine and spruce crops that are no older than 5 years and birch trees that are 2-3 years old.

There are various methods of introduction. It is most rational to spread over the surface of the soil in the spring, before it thaws, since during this period the use of wheels is possible them tractors. Agricultural spreaders are used (СТН-2,8; РТТ-4,2; РУМ-2; 1-РМГ-4, etc.).

Economic efficiency of afforestation of disturbed and produced forest areas due to mining

The main method of developing low fields for afforestation is manual planting of forest crops in ridges and dumps.

Of the methods of care, chemical weeding showed the best results, but even one-time treatment increases the cost of growing crops by 30%. The involvement of areas covered with shrubs doubles the cost of afforestation. The produced areas must be rehabilitated in the first two years after the end of mining, before the development of a powerful grass cover and before the start of the natural recovery of the willow trees.

Labor and money costs can be reduced by combining soil preparation with planting seedlings into one operation. Cultivation of low-lying fields for sown grasses (that is, for agriculture), even with the introduction of significant doses of mineral fertilizers, is relatively inexpensive for farms. And already in the first year, you can get 2-3 tons of hay per hectare, and the labor costs are 14 times lower than during afforestation.

In the conditions of medium fields, mechanization of all crop growing processes is possible. Mechanized planting without soil preparation is the most economical. Application of mineral fertilizers in medium doses ($P_{90}K_{120}$) increases costs by 35%.

The cost of developing these fields under agriculture is approximately the same. But the payback of different methods of afforestation and agricultural use differs significantly: - when growing pine, silvicultural measures are paid for in 8-21 years, spruce in low fields and in fertile areas of the middle strip - in 10-12 years, alder in flowing deposits in 11-18 years, birches in medium and high fields for 17-20 years.

Growing natural birch plantations, which are often formed in low fields, do not require any costs, but their value is always lower than timely planted pine and spruce crops with a payback period of no more than 10 years.

Cultivation of sown grasses in low fields with fertile peat pays for itself within the first year, and with a rotation of crops (3 years) can bring a significant profit. It is even more profitable to grow cereals, even such a low-yield crop as oats.

Conclusions

Therefore, deposits produced during unauthorized extraction of amber and minerals are more profitable to use in agricultural production. It is most appropriate to grow pine on fields unsuitable for meadow and field use, prepared for mineral soil and with little decomposed peat.

In areas prone to dense population of birch and willow trees, it is economically expedient to focus on the production of spruce, the costs of labor and funds for its cultivation are always lower than for the formation of pine plantations, since silvicultural care and unprofitable lighting are reduced. For growing poplar, it is better to use shallow areas of middle fields, where grain and row crops give a low yield.

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METHODOLOGY FOR DETERMINING THE PARAMETERS OF THE START OF GAS HYDRATES MASS CRYSTALLIZATION

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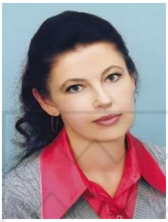

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Abstract

Man-made gas hydrates create serious problems for the oil and gas production industry. Prevention of hydrate formation requires significant costs. In addition, it is important to understand the physics and parameters of hydrate formation processes. Therefore, an urgent task is to establish the peculiarities of the kinetics and parameters of hydrate formation in technological processes. The object of the research was the parameters of the beginning of mass crystallization of gas hydrates in reservoir systems.

The process of hydrate formation at the phase boundary is manifested by the formation of a thin layer of hydrate in the form of a film. In the course of experimental studies, it was established that this process is visually fixed by clouding of the pre-specular phase boundary. The effect of distortion of the interphase boundary is explained by the formation, growth, and chaotic accumulation of gas hydrate microcrystals at this boundary. Based on the results of theoretical and experimental studies, the methodology of operative laboratory

determination of parameters of mass crystallization of gas hydrate is justified. The essence of the technique is to fix these parameters by the optical effect of distortion of the reflection of the light source on the mirror of the "liquid-gas" interphase surface.

The results of empirical studies are based on optical phenomena that were recorded on the interphase surface of the gas hydrate layer and gas. They were studied using microscopy, fixation and image processing methods. The main result of the experiments was the information recorded by the optical system and obtained after fixing the pressure and temperature.

The technique can be used to establish and operationally control the moment of mass crystallization of gas hydrates directly at the objects of the oil and gas industry (during the implementation of technological processes). This will make it possible to effectively prevent clogging of technological equipment with the solid phase of gas hydrate, as well as to prevent overuse of hydrate formation inhibitors. At the same time, the only limitation of the application of this technique may be the low light permeability of the aqueous solution as part of the formation system.

1. Introduction

Gas hydrates are formed from gases and water under certain thermobaric conditions [1]. Deposits of natural gas hydrates contain colossal volumes of methane in their composition, and man-made deposits create serious problems for the oil and gas production industry. For the formation of artificial natural gas hydrates, a necessary component is the presence of moisture in the condensed phase. In the wellbore and further along the collection and preparation system, the temperature of natural gas gradually decreases. As a result, moisture condensation occurs. The system composition and the gas mixture in it affects the conditions of thermodynamic the hydrate equilibrium [2].

Therefore, all processes of extraction, preparation, storage and transportation of oil, gas and condensate are accompanied by the possibility of the problem of the gas hydrate plugs appearance. Such processes are observed in the presence of appropriate thermobaric conditions and as a result of technological violations. As a result of reducing the internal pipelines cross-section, the operation of all technological equipment in the hydrate mode leads to a change in its operating modes, complete clogging of pipelines, fittings and equipment at oil and gas production facilities and the linear part and site facilities of mainline gas transport at UGS.

The analysis of the purpose of technological operations and equipment for extraction, preparation and transportation of natural and petroleum (associated) gas shows that a significant part of them concerns the hydrate formation prevention. Therefore, the costs of preventing this spontaneous process make up a significant part of the hydrocarbon production cost.

For prevent or remove the formed hydrates in each specific case, it is necessary to understand the physics of pipeline operation processes for different operating modes, knowledge of the conditions of gas hydrate formation processes. The thermal and hydraulic regimes of gas pipelines, the optimal humidity of transported natural gas should be taken into account. Places of possible hydrate plugs formation are determined by gas composition, thermobaric conditions, and its moisture content [3].

In the process of developing hydrocarbon deposits, a whole set of methods for preventing hydrate formation is used. The analysis of literary sources showed that all known prevention of the process methods are based on the elimination of at least one of the necessary factors: temperature, pressure or gas moisture. The classification of the most used methods of preventing the hydrates formation has the following form [4]: technological, physical and chemical methods.

The choice of methods is influenced by the existing thermobaric conditions, the possible place of hydrogenation in the technological system of gas production and transportation.

At the same time, in many cases, it is impossible to achieve the technological (hydrate-free) mode of their operation, only by maintaining the appropriate thermobaric conditions. In this case, there is a need to switch to chemical methods and the use of substances that are inhibitors of this process. Significant costs for preventing the formation of hydrates and mitigating their consequences are associated with the use of traditional thermodynamic hydrate inhibitors (TIG), such as methanol and monoethylene glycol (MEG) [5].

Therefore, management of hydrate formation processes has become necessary for safe and reliable oil and gas extraction [6]. Development of methods for detecting early signs of hydrate formation may be one such option. This will allow operators sufficient time to take appropriate measures to prevent hydrate formation.

There are various analytical methods that are used to identify the structures of gas hydrates that occur at the interface between the water and vapor phases. The study of the gas hydrates formation and dissociation is great importance for determining the conditions for safe passage of oil and gas through pipelines [7].

New methods for detecting early signs of hydrate formation have been proposed by the Center for Gas Hydrate Research at the University (Heriot-Watt). They will allow operators to have enough time to take appropriate measures [8]. The method based on the change in the gas phase composition the due to the hydrates formation is presented in [9]. This is one of these early warning methods of the gas-hydrate process.

During the formation of hydrates, the natural gas components are selectively captured in the hydrate cells, and as a result, the composition of the gas phase changes. [10]. Next, the speed of sound, thermal conductivity are determined and the equivalent concentration of the gas mixture components is established [9]. Based on this property, an experimental technique has been developed to detect early signs of hydrate crystal formation by determining the gas composition.

Yang [11] developed a reliable and fast method for detecting the composition of hydrocarbon fluid and establishing the stability zone of hydrates. The salts concentration, thermodynamic and kinetic inhibitors of hydrates is determined on the basis of the measurement of electrical conductivity and acoustic velocity data of the aqueous phase chemical composition and the stability hydrates zone is determined.

Tohidi [12] proposed a method for determining the reserve of stability of the hydrate zone based on the measurement of the water content in the gas phase. In the work [13], the authors propose monitoring systems for the prevention of hydrogenation based on dielectric properties and determination of the freezing point of the aqueous phase.

A large complex of gas hydrates properties, a diverse composition of reservoir systems, a wide range of thermobaric parameters and their fluctuations do not allow obtaining an acceptable and unambiguous result when applying most of the known methods. An important task remains the improvement of the method for operational hydrate formation forecasting in the systems of collection and preparation of industrial products, as well as the principle scheme of the equipment for its implementation.

Therefore, the purpose of this study is the theoretical and experimental substantiation of the method for determination the parameters of the moment for mass gas hydrates crystallization. Establishing and controlling the moment of the beginning for mass gas hydrates crystallization in production at the objects of the oil and gas industry will allow to manage the process of hydrate formation and prevent the appearance of ice jams in gas pipelines and equipment, by timely introduction of the necessary volumes for hydrate formation inhibitors.

2. Theoretical substantiation

The hydrates formation is characterized by an induction period, which includes the appearance of crystal nuclei and their growth [14,15]. Further, in the stage of phase transition, when the hydrate plugs formation occurs, crystals agglomeration is observed [16,17].

The hydrate formation process occurs most intensively at the interface between the gas and water phases. Processes on the liquid mirror, drops and bubbles in the laboratory reactor, technological equipment are manifested by the formation of a thin layer of hydrate in the form of a film. Specifically, the study concerned the processes that occur on the bubble surface as a surface of separation of two phases - reactor water and hydrate-forming gas in the bubble.

Visually, this process is fixed by changing the mirror surface of the phase boundary to a matte one. It has defects in the reflection of light sources, their distorted reflections and complete impermeability of light. The dynamics of the process is shown in fig. 1,2 and 3.

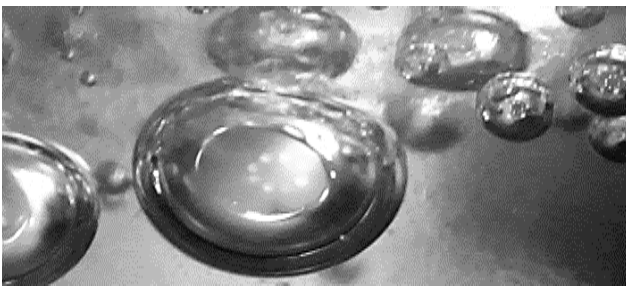

Fig. 1. Mirror interfacial surface of hydrate-forming gas bubbles in water (gas hydrate film is absent)

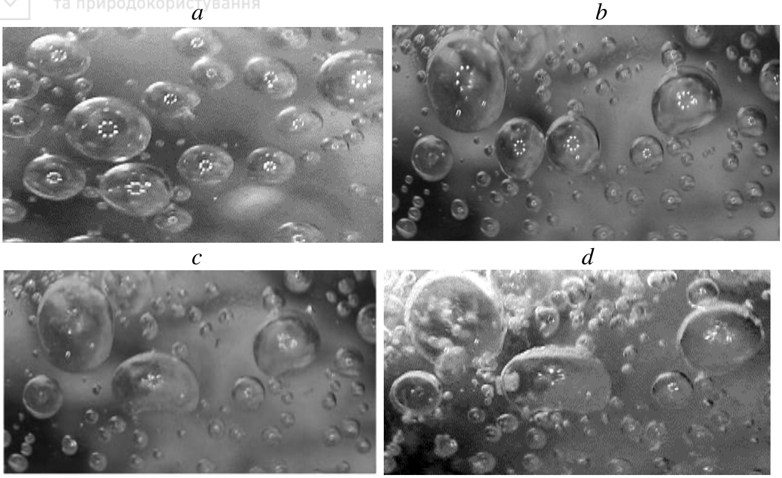

Fig. 2. Dynamics of distortion of reflections for point light sources on images of gas bubbles in water as a result of the formation of a gas hydrate film on the interfacial surface

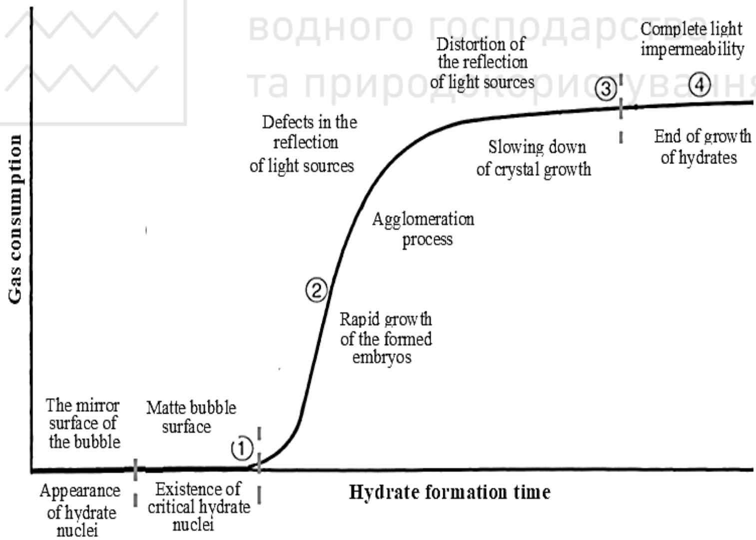

Fig. 3. The process of gas hydrates formation in water from a gas bubble

The effect of gradual the mirror distortion of the interphase boundary is explained by the formation and chaotic accumulation of gas hydrates on it. However, a significant deviation of thermobaric parameters at the initial stage 1 (matte surface of the bubble) of the control system is practically not recorded.

Therefore, the initial period of hydrate formation 1 is characterized by the nucleation of hydrate nuclei (nuclei) due to the increase in Gibbs energy ΔG. At the beginning of the hydrate formation process, water, from the point of view of the classification of dispersed systems, can be considered as an ideal solution. One of the important properties characteristic of non-colored systems of a molecular degree of dispersion is the complete passage of light, transparency, and the absence of a scattering process. Therefore, the mirror surface of the bubble is visually observed.

Further growth and overcoming the energy barrier ΔG_{cr} will lead to their reaching the critical size r_{cr}, the value of which can be calculated using the formula

$$r_{cr} = -\frac{2\sigma'_{ef} T_0}{\Delta H \Delta T}, \quad (1)$$

where ΔH - heat of crystallization of the hydrate former, kJ/mol; T_0 - equilibrium temperature of hydrate formation for the corresponding pressure, K; $\Delta T = T - T_0$ - relative cooling of the system; σ'_{ef} - effective specific surface energy of the seed, mJ/m ^{2}.

The value of the critical radius r_{cr} will decrease with the increase in the supercooling temperature ΔT for the «gas in the bubble - water in the reactor system».

As a result, a decrease in the induction time of hydrate formation will be observed. At the end of the induction period, water with formed critical nuclei of hydrates can conditionally be considered a colloidal system. It is known that the size of «true colloidal» particles lies within 1-100 nm [18].

The dispersed phase of the studied system is the nuclei of a critical size. For example, for natural gas hydrate with a density of approximately 900 kg/m^3 at T_0=278 K and ΔT=3, the radius of the critical nucleus will be r_{cr}≈15 нм, and for the hydrate at T_0=280 K and ΔT=1, the radius of the critical nucleus will be r_{cr}≈45 нм.

Scattering or opalescence is inherent among the optical properties of all colloidal systems. Scattering (opalescence) is observed when the wavelength of light is greater than the linear dimensions of the particles of the dispersed phase [19]. The light-scattering ability of dispersed systems depends on the size of the particles, the refractive index of the dispersed phase and the medium, and the wavelength of the light wave that is scattered.

Since the resolution for an optical microscope is about 10^{-7} m, colloidal particles (hydrate nuclei) cannot be seen with its help. However, it is precisely for colloidal systems that the maximum scattering of light corresponds. When the particle itself is not visible, but the scattering is quite well observed using an optical microscope under side illumination (focused light).

The sizes of the critical r_{cr} nuclei at the end of the induction time are much smaller than the wavelength of visible light ($400<\lambda<750$ nm). When light passes through a dispersed system, there is a slight scattering of light in lateral directions. As a result, a slightly matte surface of the bubble is visually observed.

The next period of rapid growth and agglomeration 2 is accompanied by further very rapid growth of the formed hydrate critical nuclei and depends on the method of heat removal of the hydrate formation process. For a reactor with a stirrer, the growth rate of hydrates is determined empirically

$$v = \alpha \Delta T^{\beta}, \qquad (2)$$

where v - rate of gas absorption during hydrate formation; α i β - constants, the values of which depend on the energy for mixing the components of the system and are determined experimentally [10].

For the process of studying light scattering in a colloidal system, when the size of the particles of the dispersed phase does not exceed 0,1 wavelength of light - for particles with a size of 40-50 nm - the Rayleigh equation is used [19]

$$I_p = \frac{24\pi^3}{\lambda^4}\left(\frac{n_1^2 - n_0^2}{n_1^2 + n_0^2}\right)^2 \gamma V^2 I_0, \qquad (3)$$

where γ - concentration of dispersed particles; V - volume of each particle; λ - wavelength of light; n_1, n_0 - refractive indices of the dispersed phase and dispersed medium; I_0, I_p - intensity of incident and scattered light.

The greater the difference between n_1 and n_0, the greater the turbidity and the stronger the scattering of light with other equivalent parameters. The sizes of the formed hydrate particles have a significant effect on the intensity of scattering of light waves. The volume of each particle is determined as $V=(4/3)\,\pi r^3$, r is the radius of the hydrate particle. Then the scattering intensity I_{scat} according to the formula (3) is proportional to the volume of the formed hydrate particles V and the radius of these particles r^6. Therefore, even with a slight increase in the linear size of gas-hydrate particles, the scattering intensity or turbidity of the colloidal solution increases quite sharply. The dependence between the scattering intensity and the linear dimensions of the particles is shown in Fig. 4 [19].

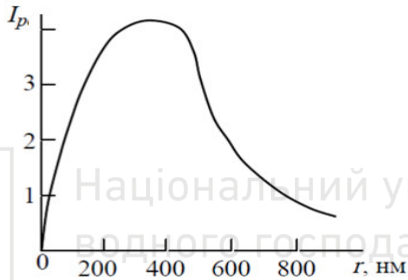

Fig. 4. Dependence of the scattering intensity on the linear dimensions of the particles

The growth of gas hydrate crystals as dispersed particles initially causes an increase in the effect of light scattering (opalescence) and increases the turbidity of the bubble surface. The uneven growth of dispersed particles leads to the beginning of the process of reflection of light waves (for the largest particles of gas hydrates, the size of which exceeds the light wavelength λ). As a result, light reflection defects on the bubbles are visually observed.

The next period 3 is the slowing down of the growth of hydrate particles. Volume diffusion growth of crystals will be observed on the free surface of the bubble and the already formed gas-hydrate crust. The rate of formation of gas hydrates will be determined by calculating the mass rate of water diffusion M_v through a flat hydrate film of thickness h and surface F [20]

$$M_w = D_w \cdot \frac{F \cdot \Delta f \cdot \rho w}{h}, \qquad h = \sqrt{\frac{2Dw \cdot \Delta f \cdot \tau}{n}}, \tag{4}$$

where D_v - the diffusion coefficient of water through the hydrate film (for natural gas with a relative density of 0,6 D_v=10^{-6} sm^2/s); Δf – difference in volatility of water vapor over liquid and hydrate; ρ_v - density of water in the hydrated state ρ_v=0,757-0,792 g/sm^3; h - hydrate film thickness during hydrate formation τ; n - mass ratio of water and gas in the hydrate.

For this kinetics period of gas hydrate formation, the linear dimensions of the particles of the dispersed phase will exceed the length of the light wave λ that passes through the dispersed system. Then they will observe its reflection, not scattering. Visually, this manifests itself in the distortion of the reflection of light sources.

The last period 4 is the end of the hydrate formation process. We have a thick, dense crust that covers a bubble of gas that is not part of the gas hydrate. At the end of the hydrate formation process, complete light opacity is visually observed. A dense crust does not let light through.

Thus, taking into account the information obtained in the process of the performed analysis, it is possible to record the earlier stages of the hydrate formation process and the moment of the beginning of mass crystallization.

Structurally, the task of low-dose gas introduction into the liquid volume in the reactor for its bubbling mixing with simultaneous control over the processes on the surface of the formed bubbles can be realized by mounting a gas introduction line through a capillary immersed in the liquid. However, this study is narrowly focused and concerns the processes of hydrate formation on the surface of a stationary bubble formed on a section of a vertical capillary in a liquid volume.

The periodicity of the formation of bubbles is appropriate for acceptable mixing of the sample in the study area and the possibility of capturing high-quality images at the level of 0,5-5,0 bubbles per minute. Therefore, it is advisable to place the gas supply capillary horizontally with an oval-shaped opening on the lower side (Fig. 5).

Consider the speed of movement of bubbles that will be formed in the case of horizontal placement of a capillary with a cut end at an angle of 45° for supplying gas to the reactor. This position and shape of the capillary opening makes it easy to organize and hold a certain volume of gas in the form of a displaced bubble. At the same time, a bubble in the form of a hemisphere attached to the section of the capillary is formed as a result of the balancing of the forces of surface tension, gas pressure in the capillary and pushing out by a denser liquid.

To understand, let's take a closer look at the peculiarities of gas movement and the processes that will take place in the reactor. We will assume that the flow of gas entering the water from a horizontally placed capillary consists of individual spherical bubbles. Let us dwell on the process of formation and movement of one such bubble.

The time of a complete bubble cycle τ consists of:

- time τ_1 - from the moment of nucleation to separation from the capillary;

- time τ_2 - waiting time during renewal of the conditions (pressure difference in the capillary and above the reactor) necessary for the initiation of a new bubble on the capillary.

Then the bubble separation frequency f will be calculated as $1/\tau$.

Let the capillary in the reactor have a diameter d_{cap} and be placed at a depth h from the surface of the reactor liquid. The dimensions of the bubble when it is separated from the capillary section will be determined by its diameter d_{sep} (conditionally - the diameter of the separation), moreover, $d_{cap}<d_{sep}$. Such a gas-filled bubble will have some volume V.

During the entire time τ_1, the bubble will be acted upon by the force of gravity $F_{grav.}$, the force of surface tension $F_{sur.ten.}$ and the repulsive force of Archimedes $F_{Arch.}$ (Fig. 5).

In the process of bubble growth, the first two forces will prevail over Archimedes' force, but will balance out over time

$$\overrightarrow{F_{grav}} + \overrightarrow{F_{sur.ten.}} - \overrightarrow{F_{Arch}} = \vec{0} \qquad \overrightarrow{mg} + \overrightarrow{\sigma \pi d_c} = \overrightarrow{\rho_w g V_{bub.}}, \quad (5\text{-}6)$$

where m - mass of gas in the bubble; g - free fall acceleration; σ - surface tension of water; ρ_w, ρ_g - density of water and natural gas; π = 3,14; V_{bub} - the volume of the bubble.

After mathematical transformations, the equation for determining the diameter of the bubble at the time of separation can be written in the form

$$d_w = \sqrt[3]{\frac{6 d_c \sigma}{g(\rho_w - \rho_g)}} \quad (7)$$

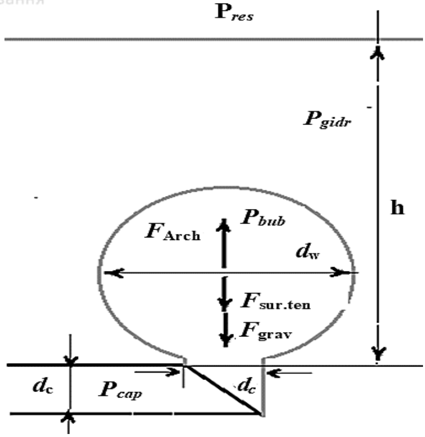

Fig. 5. Forces acting on the bubble

The gas density in the bubble is unknown, therefore, to determine ρ_g, consider the change in pressure in the «capillary - bubble» system. Gas pressure in a stationary bubble according to Bernoulli's law

$$P_{res} + P_{gidr} + P_{din} = P_{bub} = P_{cap} \tag{8}$$

where $P_{\text{рез}}$ - pressure in the reservoir, MPa; $P_{gidr}=\rho_w gh$– hydrostatic pressure of the water column; $P_{\text{din}}=\rho_g w^2/2$ - dynamic pressure of the moving gas (for a stationary bubble w=0 m/s); P_{cap}– gas pressure in the capillary; P_{bub}=$_{cap}$ - pressure in the bubble.

Based on the gas density ρ_g, we calculate the diameter of the separation of the gas bubble from the capillary d_w.

The speed of movement of the bubble when rising to the surface, taking into account the condition $\rho_w >> \rho_g$ [21] can be calculated by the equation

$$w = \sqrt{\frac{4 d_w g}{3C}} \tag{9}$$

where C - coefficient of resistance of water in the reactor.

The C coefficient in the event that the conditions are met, namely for the Weber criterion We>1, the Reynolds number Re>600 and the Bond criterion BO<13, can be calculated by the Harmonti formula [17]

$$C = 0{,}568\sqrt{BO}, \quad BO = \frac{g d_w^2 (\rho_w - \rho_g)}{\sigma} \tag{10}$$

3. Experimental study

Even under such conditions, it is quite difficult to record the moment of «clouding» of the interphase surface as clearly and unambiguously as possible [22].

However, together with the process of clouding of the interphase surface, a gradual distortion of the reflections of light sources on it is observed. The beginning of their distortion was recorded much earlier than the visual signs of clouding of the mirror interfacial surface (bubbles in a liquid or drop in a gas atmosphere). The dynamics of this process is illustrated in fig. 2.

However, there are practically no other visual signs of the beginning of the hydrate formation process, except for the distortion of the reflection of light sources (Figs. 2*b* and 2*c*). This optical effect allows extremely sensitive (with high accuracy) to record the changes occurring at the micro level with the mirror interphase «gas-liquid» interface. It allows you to record the process of the beginning of the growth of critical nuclei and the transition to rapid mass crystallization.

Therefore, the moment of fixation of the optical effect of distortion of the reflection of the light source on the mirror of the «liquid-gas» interphase surface by microcrystals of gas hydrate can be used as the basis of the method of setting the parameters of the moment of mass crystallization of gas hydrates for complex reservoir systems under industrial production conditions.

4. Peculiarities of laboratory research

The simplest and most informative is the method of visual observations. This method is used in the study of gas hydrates. For example, in [23], the behavior of clathrate hydrates during crystal growth was studied using an optical cell under pressure. The method of quantitative measurement of film thickness using microscopy is described in [24]. Freer [25] used optical microscopy as a tool to determine the rate of growth of a methane hydrate film under the influence of temperature changes.

Therefore, in the process of research and verification of the methodology, the authors recorded and analyzed photo and video images of the processes of formation of gas hydrates in multicomponent gas mixtures (natural gas) when in contact with aqueous solutions. The research was carried out on the laboratory device shown in fig. 6.

Fig. 6. Laboratory installation: appearance and research process

In the course of research, the optimal level of image magnification was analyzed for maximum informativeness and technical implementation on laboratory equipment. The limitation concerns the magnification of the received image. During laboratory testing of the technique, it was established that increasing the image by more than 150-200 times will make it difficult to find the object under investigation behind the glass of the reactor viewing window, especially during bubbling, and to assess the overall picture of the process. Since the main investigated objects are mainly colorless and transparent, the illumination of the reactor contents by sources of different colors has become quite effective.

Thus, the proposed technique consists in setting the parameters of the moment of mass crystallization of gas hydrates based on the fixation of the optical effect of the distortion of the reflection of the light source on the mirror of the «liquid-gas» interphase surface.

5. The results of the experiment

Natural gas of the following composition was used for the analysis of the proposed express method, %: CH_4 - 87,17; C_2H_6 - 5,16; C_3H_8 - 2,48; *i*-C_4H_{10} - 0,67; *n*-C_4H_{10} - 0,90; *i*-C_5H_{12} - 0,12; *n*-C_5H_{12} - 0,17; C_6H_{14} - 0,17; C_7H_{16} - 0,28; CO_2 - 0,17; N_2 - 2,50; He- 0,21.

During preparatory operations, namely water preparation, it is necessary to saturate the water with hydrate-forming gas. Natural gases have the property of dissolving in liquid and thermobaric conditions have a significant effect. Water saturation in the reactor will be accompanied by a slight pressure drop. This was taken into account during experimental studies.

To evaluate the proposed express method of determining the beginning of mass crystallization of gas hydrates, it was necessary to perform a number of experiments.

The investigated parameters are the pressure in the reactor and the temperature at the moment of mass hydrate formation. According to the data obtained during the experiments, the curves of the beginning of mass hydrate formation for the indicated composition of natural gas were constructed (Fig. 7).

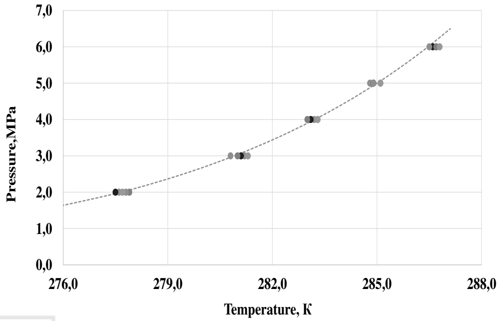

Fig. 7. Evaluation of the method of setting the parameters of the beginning of mass gas hydrate crystallization: – experimental data; ------ – is the equilibrium curve of hydrate formation, calculated according to the Barrer-Stewart equation

Conclusions

Therefore, the proposed technique consists in setting the parameters of the moment of mass crystallization (hydrate formation) based on the fixation of the optical effect of the distortion of the reflection of the light source on the mirror of the liquid-gas interphase surface.

The process of hydrate formation at the phase boundary is manifested by the formation of a thin layer of hydrate in the form of a film. Such a process is visually fixed by the transformation of the mirror surface of the phase boundary into a matte one. The effect of distortion of the interphase boundary is explained by the formation, growth, massive and chaotic accumulation, placement of hydrate microcrystals on this boundary. Simultaneously with the process of clouding of the interphase surface, a significant distortion of the reflection points of the light source occurs. The investigated optical effect allows to record with high accuracy the changes occurring at the micro level on the mirror interphase «gas – water» surface.

Thus, the proposed method consists in establishing the parameters of the moment of mass crystallization of gas hydrates based on the fixation of the optical effect of the distortion of the reflection of the light source on the mirror of the «liquid – gas» interphase surface. It can be used to establish and control the moment of mass crystallization of gas hydrates in production at the facilities of the oil and gas industry, which will allow to manage the process of hydrate formation and prevent the appearance of ice jams in gas pipelines and equipment, by timely introduction of the necessary volumes of hydrate formation inhibitors.

The only limitation of the application of this technique will be the low light permeability of the aqueous solution as part of the formation system.

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METHODS OF RECOGNITION IN THE METHODOLOGY OF ENERGY-EFFECTIVE INVARIANT CONTROL OF CRUSHING-CLASSIFICATION OF ORE DURING ENRICHMENT

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Abstract

The object of the research is the processes of managing the technological redistribution of ball grinding of iron ore at ore processing plants in closed cycles, including a mill, a mechanical single-spiral classifier and a spiral feeder. The subject of the research is a complex of automated systems for the implementation of energy-efficient invariant control of grinding and classification of ores as part of the automated process control system of the first stage of ore preparation based on the developed methodology and indirect predictive estimates of the characteristics of raw materials and equipment. The methodology of the article is considered as a set of research methods in accordance with the specifics of the object of knowledge and is based on the principles of the unity of theory and practice, certainty, concreteness, recognizability, objectivity, causality, development. The aim is to increase the efficiency of the ore preparation technological process by applying a new developed methodology for the implementation of energy-efficient invariant control of grinding ore classification based on indirect predictive estimates of the characteristics of raw materials and equipment. It is shown that the system of selected methods, including a number of general scientific and special ones, as well as those proposed (more than 20 methods), makes it possible to solve the overwhelming majority of general issues of the implementation of energy-efficient invariant control of grinding-classification of ores, which increases the accuracy of assessing technological parameters and, as a result, quality indicators. control processes within the framework of technological requirements. It is proved that a ball mill can be represented by the initial and main parts of the drum and ball loading, and the mechanical single-spiral classifier can be represented by a double-pass spiral, the upper part of the spiral with a sand product and a sand gutter, a classifier basin with a lower part of the spiral and a drain threshold, which are independent. autonomous systems, where processes run independently and practically do not affect each other, which will allow the use of independent automatic control systems and the ability to take into account additional useful connections between controlled processes, which will lead to a further improvement in the quality of the complex of systems.

1. Introduction

Ukraine produces a significant part of ferrous metallurgy products and raw materials for it - iron ore concentrate, which accounts for the overwhelming majority of revenues from the export of these products. The higher cost of domestic products in comparison with foreign counterparts puts Ukraine in different conditions on the world market. This is due to the fact that the iron ore concentrate, from which more than half of the metallurgical products are now produced, is distinguished by a higher cost due to significant cost overruns of electricity, materials in the form of balls and lining and the production of a sub-standard product when grinding ore, especially in the first stages of ore preparation. One of the ways to improve ore preparation is to improve the automatic control of this technological process, since the automated control systems used at domestic ore processing plants do not meet modern requirements in many ways. At the same time, scientists and practitioners point to possible ways to improve the situation. Initially, this refers to the improvement of the grinding medium of ball mills, the transition to direct methods of controlling the volumetric filling of mills with ore, the use of such important parameters as the viscosity of the pulp, the speed of movement of the pulp along the drum, liquefaction of the pulp in specific situations, energy efficiency of destruction. As shown by inspections at operating enterprises, due to the risk of overloading mills and putting them into emergency mode, operators reduce productivity by at least 10-15% [1].

2. Actuality of the paper

The foregoing, first of all, indicates that this situation is generally due to the imperfection of existing methodological approaches to solving the problem, as well as methods, models and tools for automated control of the process of grinding ore by ball mills operating in a closed cycle with mechanical single-spiral classifiers. As a result, the enrichment indicators deteriorate, and in the face of an increase in the cost of iron ore concentrates, the industry suffers significant damage. Therefore, the transfer of automated control of ball grinding of ore to a qualitatively higher level by implementing progressive ideas for organizing control systems based on new or improved mathematical models and established dependencies for this equipment, methods and systems of invariant energy-efficient automated process control in conditions of iron ore processing plants, approaches and means evaluation of the main technological parameters is an urgent scientific problem. Of course, such a transition can be carried out on the basis of a new developed methodology for energy-efficient control of the grinding-classification of ores based on indirect predictive estimates of the characteristics of raw materials and equipment.

3. Unresolved parts of a common problem

Among the unresolved parts of the problem, one can single out the processes of controlling the technological stages of ball grinding of iron ore at ore-dressing plants in closed cycles, including a ball mill, a mechanical single-spiral classifier and a volute feeder, as well as a complex of automated systems for implementing energy-efficient invariant control of grinding-classification of ores as part of an automated control system technological process of the first stage of ore preparation based on the developed methodology and the methodology itself for the implementation of these automated control systems.

4. Aim of the research

The aim of this work is to develop a methodology for implementing energy-efficient invariant control of ball grinding-classification of ores based on indirect predictive estimates of the characteristics of raw materials and equipment.

The formulated aim of the work necessitated the solution of the following tasks:

- briefly describe the essence of the methodology of knowledge;
- consider and analyze the methods of cognition in technical systems;
- consider the essence of empirical research methods and their suitability for the developed methodology;
- determine the place of special methods of cognition in this methodology;
- to establish the role of the general special method of knowledge
- the decomposition method in the methodology of energy-efficient invariant control of ball crushing and ore classification based on indirect predictive estimates of the characteristics of raw materials and equipment.

5. Method

5.1 Methodology of cognition

Methodology is a rather complex concept, since it covers different areas, starting with philosophy. However, it can be represented as a set of research methods used in any science in accordance with the specifics of the object of its knowledge. It implements the following functions: determination of methods for obtaining scientific knowledge that reflects dynamic processes and phenomena; direction, prediction of special ways, where a certain research goal is achieved; ensuring the comprehensiveness of obtaining information about the process or phenomenon under study; organizing the use of new knowledge in practical activities, etc.

The methodology of cognition is based on the principles of the unity of theory and practice, certainty, concreteness, recognizability, objectivity, causality, and development.

In methodology, it is customary to single out the object, subject and purpose of the study. The processes of controlling the technological stages of grinding iron ore at ore-dressing plants in the first stages belong to closed cycles, which include a ball mill, a mechanical single-spiral classifier, a scroll feeder and raw materials coming from quarries and crushed to a given weighted average size. Deposits of poor iron ores in Ukraine are quite diverse. Even the ores of one quarry are divided into several technological varieties.

The methodology is based on the method – a system of rules and techniques for studying the object and subject of research. According to the degree of generality and scope, methods can be conditionally represented in the form of four main groups: general or philosophical, operating in all sciences and at all stages of knowledge; general scientific, used in the humanities, natural and technical sciences; partial (with an interdisciplinary scope); special – for specific sciences.

5.2 Methods of knowledge in technical sciences

In technical sciences, general scientific research methods are mainly used, which are represented by empirical research methods, theoretical research methods and general logical research methods. For empirical research in this work, the methods of experiment, comparison, description and measurement are most suitable. Among the methods of theoretical knowledge, hypothetical and ascent from the abstract to the concrete may be the most suitable. General logical methods are most commonly used here – these are analysis and synthesis, abstraction, idealization, generalization, induction, deduction, analogy, modeling, system analysis, statistical methods.

Empirical scientific research is primarily aimed at revealing facts and laws that establish through the generalization and systematization of the results obtained in relation to technical systems through experiments. Theoretical studies consider processes more abstractly. In them, under normal conditions, it is impossible to study and observe objects. The empirical and theoretical levels cannot be separated from each other, although they have a certain autonomy. However, above the empirical level, the superstructure is always the theoretical one. A feature of the theoretical level is that ideal objects are used here. The theoretical level is based on empirical data. However, the result obtained by empirical research depends on theoretical concepts. The results obtained by empirical research reflect reality only when they can be explained from the standpoint of certain theoretical concepts. The facts obtained in the process of scientific research become scientific knowledge only when they can be presented in a systematic scientific form. It should be borne in mind that the experiment is the basis for the formation of hypotheses and theories, serves as a criterion for the truth of the theoretical results of the study. However, the determining side of the experiment is always theory. The theoretical method is the highest level of scientific research, where idealization and mental experience are especially of fundamental importance. An imaginary experiment is carried out on an idealized object, intellectually controlled and analogous to the material. The algorithm of the theoretical level of research can be represented by the following chain: imaginary experiment and idealization based on the results of practical actions; presentation of results in logical forms; logical verification of the validity of theoretical results; application of theoretical results in practice.

General logical research methods are widely used in the cognition of technical objects. The use of general logical research methods can be represented as follows. The method of analysis should be applied when studying the influence of factors on the wear of balls in a mill, the use of balls of different sizes, structural relationships between pulp parameters in the classification process, the influence of bed placement and spiral dynamics on the output of the finished product, the behavior of individual components of a ball mill and a single-spiral classifier during operation. The synthesis method must be used when combining the dissected and analyzed parts of a ball mill and a mechanical single-spiral classifier into separate units and together them into a grinding cycle. The idealization method should be applied in theoretical studies, where it will be necessary to neglect certain facts that will not lead to a distortion of the results obtained. This is the supply of crushed hard particles in the form of particles of a cubic or spherical shape, the neglect of an insignificant amount of material when determining the volume of sand between the turns of the spiral of a mechanical single-spiral classifier. Generalization allows an imaginary transition from individual facts to a more general concept or judgment. This in this work makes it possible to conclude on the nature of the propagation of the magnetic field in the electromagnetic system used to assess the weighted average size of the crushed material in the unloading of the mill and the sands of the mechanical single-spiral classifier. Analogy is a method in which, thanks to knowledge about a known object, they are transferred to an unknown, but similar object. In this case, it is necessary to adhere to the following requirements: basing on the essential features of objects and as many common properties as possible; tightness of links between comparable features; establishing not only similarities, but also differences between objects. In this method, conclusions are drawn by analogy. The method of analogy is the basis of modeling, ie it is used in conjunction with other methods. In this paper, it is advisable to apply it together with the experiment. Then it is called a model experiment, which is expedient to carry out by proving the adequacy of determining the volume of sand between the turns of the spiral by a theoretical approach. Modeling is a method of studying objects on their models. At the same time, complex objects are replaced by models that are specially created and are more convenient. In the work of modeling, you need to use quite extensively. Usually they model either the structure of an object or its behavior. Simulation provides reliable results when the model closely matches the real object.

The systems approach serves as the foundation of systems engineering, which studies the problems of analysis and synthesis of complex information and control systems based on computer technology. For such systems, it is almost impossible to create a general theory for solving specific problems. Therefore, in systems engineering, the place of theory in a certain sense was replaced by a model. And yet, several components are distinguished in it that complement each other - these are empirical-intuitive, deductive-axiomatic, constructive and associative. Any act of cognition is based on these components, and the process of cognition is simultaneously directed from the individual parts of the object to the whole and from the whole to the parts. In addition, the systematic approach is usually based on the following provisions: each part of the object is described not in isolation, but taking into account its influence on the entire object; the object is not limited to the characteristics of its constituent parts, but takes into account the relationship between them; hierarchical structure of the system; taking into account the operating conditions of the system; taking into account the dependence of the state of the system on its components and the state of the components on the state of the entire system; the practical impossibility of taking into account only the analysis of the functional characteristics of the object under study, since it is often important to establish the functioning of the entire system; if the source of the change in the state of the system is in itself, the prerequisites for its self-government are taken into account. In this method, when studying any problem, it is advisable to single out several interconnected main subproblems: problem identification, description, formulation of criteria, idealization, decomposition, composition, solution. In this work, it is advisable to apply this method when creating a hierarchical system for ensuring the solid/water ratio in a ball mill, taking into account the initial feed, its size, and the liquefaction of the sands of a mechanical single-spiral classifier.

Statistical research methods should be used in processing experimental data, determining the errors of information tools and control systems, and proving the adequacy of models to real processes. The specificity of the object under study gives preference in the use of certain methods. In technical research, so-called special methods are also widely used, which are specific to specific objects under study.

5.3 Methods of empirical research

Empirical research methods - experiment, comparison, description, measurement also occupy an important place in the study of energy-efficient invariant control of grinding and ore classification based on indirect predictive estimates of the characteristics of raw materials and equipment.

An experiment is understood as a system of cognitive operations carried out in relation to objects placed in specially created conditions that contribute to the identification of the sought-after objective connections. In technical objects, two main areas for experiments should be distinguished, conducting laboratory and industrial research. The results of experiments serve as criteria for the truth of theoretical knowledge, despite the fact that theory is the defining side of the experiment. In laboratories, experiments should be carried out on physical models. So, on a physical model of the interturn space of the spiral, made in full size, it is possible to remove the dependence of the volume of sands on their height along the vertical passing through the point of contact of the cylindrical bed and the lower edge of the feed turn. It is possible to remove the dependence of the volume of sands along the horizontal on their surface at different heights. According to the developed methodology, it is possible to conduct laboratory experimental studies of nodes that are not mathematically accurately described. The program of such research should include the processes and tools shown in Fig. 1. As can be seen from Fig. 1, there will be ten such studies. In addition, it is necessary to conduct experimental studies (tests) of the grinding-classification cycle under production conditions in order to obtain data for linking the results of a theoretical nature and modeling to real technological processes. After experimental studies, it is necessary to consider the issues of practical implementation of a complex of energy-efficient invariant control of ball grinding-classification of ores based on indirect predictive estimates of the characteristics of raw materials and equipment.

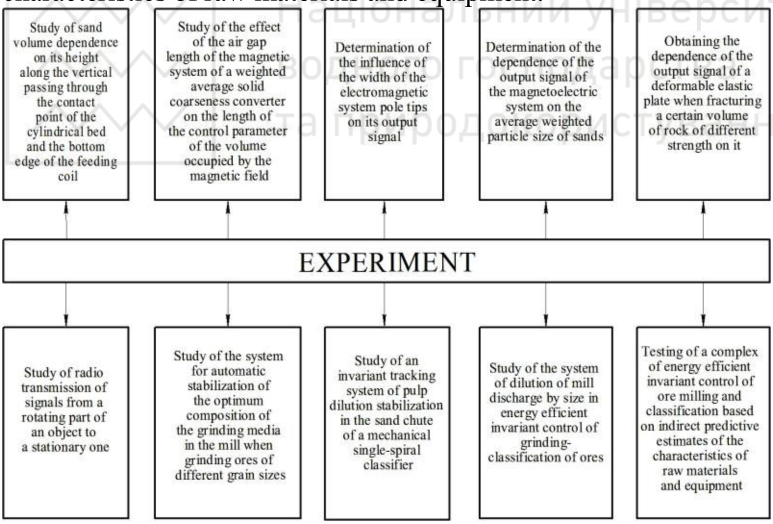

Fig. 1. Scheme of experimental studies of a complex of energy-efficient invariant control of grinding-classification of ores based on indirect predictive estimates of the characteristics of raw materials and equipment

The method of comparison in this work should also be widely used when considering tabular and graphic material. The areas of application of the method are shown in Fig. 2. As can be seen from

Fig. 2, the method covers almost all components of the complex: ball loading, lining wear, classifier bath, sand volume between spiral turns, classifier sand trough, information transmission channel, pulp movement along the mill drum and energy efficiency of ore grinding in a ball mill.

Description is a specific method of obtaining empirical knowledge, the essence of which is the systematization of data obtained using other methods, which serves as the basis for further logical operations. In this case, the object of study is reflected as a whole. The description is carried out by means of the language, tables, graphs, diagrams, series, indices, etc. In the work it is used almost continuously, where such fragments are obtained.

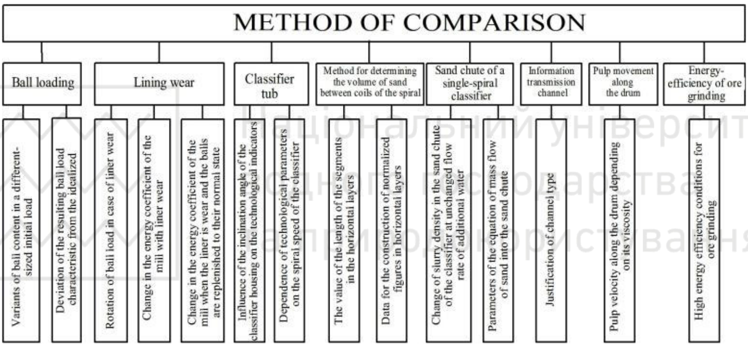

Fig. 2. Areas of application of the comparison method in creating a complex of energy-efficient invariant control of grinding-classification of ores based on indirect predictive estimates of the characteristics of raw materials and equipment

The measurement method is a system for recording the quantitative characteristics of the object under study and should be used in all experimental studies of this work. In technical systems, it requires taking into account the unity of quantitative and qualitative aspects, which makes it possible to mathematically reproduce the quantitative and qualitative characteristics of an object in an experiment.

In addition to experimental studies, measurements (estimates) are also used in the management of objects. Often, already known information tools are used for this, however, when managing new processes or moving to a qualitatively higher level with already known objects, there is a need for new methods for measuring parameters. The analysis showed that during the transition to a qualitatively higher level of management and the implementation of energy-efficient invariant control of the grinding-classification of ores based on indirect predictive estimates of the characteristics of raw materials and equipment, it is necessary to develop 21 new methods of measurement (estimation). They are shown in Fig. 3. As can be seen from Fig. 3, the new methods include mechanical single spiral classifier sands, ball mill initial parameters, mill pulp condition, ore grinding energy efficiency, ore grinding and ball loading. Most of these parameters have never been operationally evaluated.

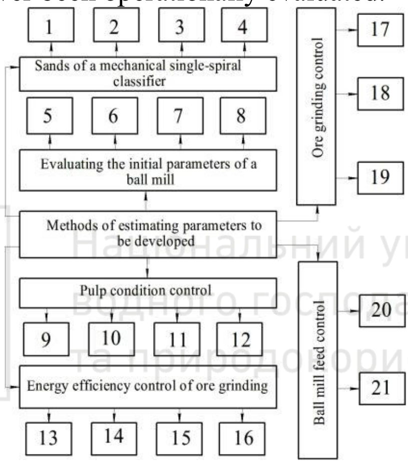

Fig. 3. Estimation of parameters by methods that do not exist and that need to be developed for energy-efficient invariant control of grinding-classification of ores based on indirect predictive estimates of the characteristics of raw materials and equipment: *1* - method of indirect predictive assessment of sand consumption; *2* - method for determining the instantaneous values of the flow rate of sands; *3* - method for estimating the height of sands in the interturn space of a spiral; *4* - sand volume measurement error compensation method; *5* - method for measuring the ore size of the initial feed; *6* - method for measuring the size of sands of a mechanical single-spiral classifier; *7* - method for estimating the size of ore at the ball mill inlet; *8* - method for ensuring a given solid/water ratio at the inlet of a ball mill; *9* - pulp viscosity evaluation method; *10* - assessment of pulp movement along the ball mill drum; *11* - method for determining the speed of movement of the pulp depending on the viscosity; *12* - method of providing a fictitious speed of movement of the pulp by changing its viscosity; *13* - criterion for assessing the energy efficiency of ore grinding; 14 - method for determining the energy efficiency of ore destruction; *15* - method for evaluating the energy efficiency of ore breaking in mills with high pulp levels; *16* - method for evaluating the energy efficiency of ore breaking in low pulp mills; *17* - method of fixing the basic parameters of the crushed ore; *18* - method for assessing the thickness of the lining in a ball mill; *19* - method for accounting for

lining wear and ball load slippage in a ball mill; *20* - method of indirect prognostic estimation of the state of optimal ball loading; *21* - method for determining the number of balls to be loaded into the mill

5.4 Special methods of cognition

In addition to general scientific methods for studying technical objects, so-called special methods should be used. The use of certain special methods is determined by the specifics of the object under study. Many technical sciences have given rise to a huge number of special ways of research. The field of science in the specialty "automation of control processes" primarily includes methods of the theory of automatic control and its individual parts – the method of invariance, methods of adaptive systems, optimal systems, servo systems, mathematical forecasting, stabilization of operating modes of technical systems, other means, statistical dynamics of systems control, spectral theory of signals, signal filtering theory, minimax criterion, superposition method, algorithmic method, etc. As auxiliary methods, methods of the theory of random processes, metrology, measurement errors, information tools, sensitivity, methods of the theory of accuracy, approximation of dependencies, transitional actions are used. All of these methods can be used in the process of solving this problem.

Among the special methods, one can single out those that are used for various technical sciences, in other words, general special methods. These include methods of decomposition and composition, systems theory, theory of experiments, hydraulics of Newtonian fluids, etc. Most of these methods also need to be applied when solving this problem.

As grinding agents in the first stages of ore preparation, ball mills with a high drain level and central unloading of the МШЦ 4.5×6.0 type are mainly used, however, the most promising are technological units with a low pulp drain level and three-phase ball movement, which have great advantages over others [2]. In [2] it is shown that the ball mill is a complex control object. The analysis found that the mechanical single-spiral classifier is the same. Therefore, it is supposed to use a large number of methods of this group of their knowledge. A special place should be occupied by the decomposition method, which makes it possible to simplify the study of complex aggregates by representing them in the form of separate units and parts.

Central among the special methods of this work are the methods of the theory of automatic control, the theory of the radio engineering method and improving the accuracy of information tools. Among the ways to improve the accuracy of information tools, their own, related to the peculiarities of their device, operation and implementation principle, should prevail. Methods of the theory of radio engineering systems cover the transmission and reception of radio signals at high frequencies. The methods of automatic control theory should be widely used. They should cover all technological units of the grinding cycle and the most important processes. To achieve the set goals, it is necessary to apply a large number of basic science methods in the direction of research in this work, as shown in Fig.4. As can be seen from Fig. 4, there are basically ten such methods.

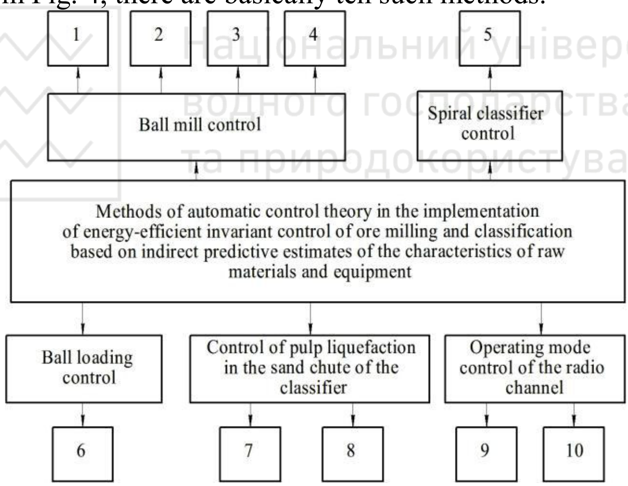

Fig. 4. Methods of the theory of automatic control, which should be applied in the implementation of energy-efficient invariant control of grinding and classification of ores based on indirect predictive estimates of the characteristics of raw materials and equipment: *1* - software methods for determining ore productivity and pulp liquefaction and the theory of digital systems; *2* - methods of multilevel automatic control of pulp liquefaction; *3* - methods of the theory of closed systems when loading ball mills with ore; *4* - methods for developing mathematical models of controlled objects when finding the transfer function of the mill according to the energy efficiency of ore grinding; *5* - methods of invariant control when dividing the discharge of the mill into overflow and sands; *6* - methods of flexible cyclic control of

the supply of balls to the mill; *7* - follow-up control methods for liquefying classifier sands; *8* - methods of invariant control at liquefaction of classifier sands; *9* - methods of strict cyclic control in coordinating the actions of individual nodes; *10* - methods of cyclic continuous control with mode memorization

5.5 General special methods - decomposition method

The study of a ball mill [2,3,4] as a controlled object was carried out in [5], which shows that it has the main features noted in [6] and therefore belongs to complex control objects. The mechanical single-spiral classifier is the same object [7,8]. Together, in the ore grinding-classification cycle, they form an even more complicated object, which is rather difficult to control [9], and it is not surprising that the necessary indicators of automatic control have not been achieved here for a long time.

The decomposition method [10,11] is ideal for studying such complicated objects. The idea of decomposition is to simplify the task of studying a complex object by analyzing its structure with subsequent transformation - dividing into simpler components. Moreover, each selected element is simpler than the original object. In addition, often in the process of selecting individual parts, the number of inputs and outputs of each such element is reduced compared to the original object. All this greatly simplifies the study of the entire object. Often, a technical system, in accordance with its characteristics, is divided into separate subsystems with a certain autonomy. In the understanding of automatic control, such subsystems can be controlled not from a system-wide device, but from a local regulator. When decomposing, it is advisable to divide the object into constituent elements according to its structure, using weak links or their practical absence between the separated parts. In the studied cycle of grinding-classification of ores, such weak links between individual components are observed.

The most common technological cycle for grinding-classifying low-grade iron ores at concentrating plants contains a ball mill with a volute feeder and a mechanical single-spiral classifier operating in a closed cycle. The decomposition of the technological cycle, firstly, involves the separation and separate consideration of both a ball mill and a mechanical single-spiral classifier. Secondly, these individual technological units are supposed to be divided into smaller and at the same time practically independent structural components. In such a division, it is necessary to consider in detail the operating parameters and characterize their impact on the operation of both each structural unit and each node, as well as the classification grinding cycle as a whole. It is necessary to disclose incoming, outgoing quantities and disturbing factors. Disturbing factors should be analyzed in detail, their impact on the process should be identified and evaluated, and the methods of neutralizing the negative impact should be considered.

The technological cycle of grinding-classifying low-grade iron ores can be represented as two autonomous systems - a ball mill and a mechanical single-spiral classifier, as shown in Fig. 5, where DF are disturbing factors.

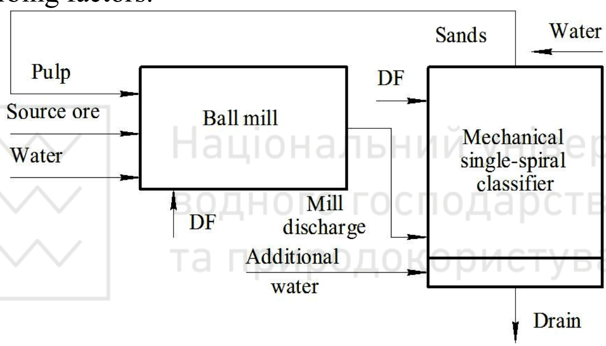

Fig. 5. Decomposition of the grinding cycle of low-grade iron ore into a ball mill and a mechanical single-spiral classifier

The initial ore, water and pulp created by the sands of a mechanical single-spiral classifier and water added to them are fed to the cycle inlet to the ball mill. The mechanical single spiral classifier at the inlet receives mill discharge and additional water. The loop output is the classifier drain parameters. Perturbing factors of the DF (Fig. 5) are applied to each of the technological units, which deviate the process from the normal mode.

The analysis showed that a ball mill and a mechanical single-helix classifier can be fed by five almost autonomous components each, as shown in Fig.6. The ball mill is represented by the volute feeder, the initial part of the drum, the main part of the drum, the ball load and the electric drive of the drum. The mechanical single-spiral classifier contains a two-start spiral, an electric drive of the spiral, a classifier bath with the lower part of the spiral, an upper part of the spiral with a sand product and a sand chute. Disturbing factors of the DF act on each of the selected autonomous parts (Fig. 6). The general perturbing factor of the cycle is the original ore, the properties of which can vary within fairly wide limits. It was shown in [12] that ores at the first stages of grinding at ore-dressing plants are represented by several technological types. Thus, the totality of the ore of a particular open pit can be represented by several separate types. In other words, it is possible to decompose raw materials into six separate types with their own specific technological properties - strength, density, magnetic iron content, fineness of inclusions of a useful component. It is much easier to study and process a separate technological variety of ore, however, for the most part, they are formed according to similar characteristics into almost two technological varieties.

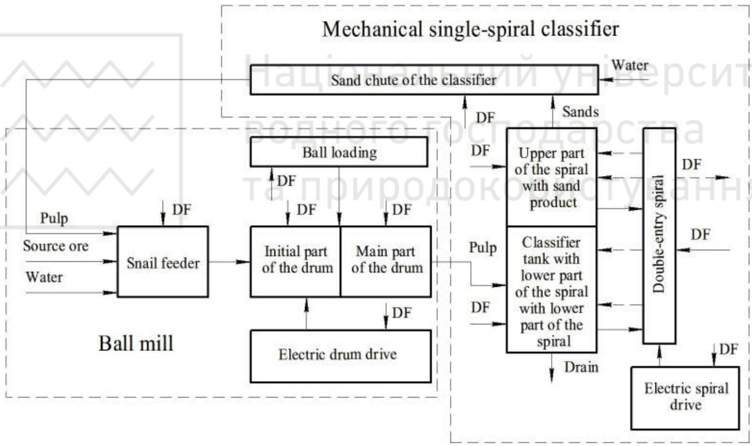

Fig. 6. Decomposition of the grinding-classification cycle of low-grade iron ores into a ball mill and a mechanical single-spiral classifier and into their components

From the analysis of Fig. 6, it follows that different components of the decomposition of the ore grinding-classification cycle make different contributions to its general properties. In this case, the nodes that have less effect on the general properties of the grinding-classification cycle of ores include a volute feeder, an electric drive of a ball mill, and an electric drive of a spiral of a mechanical single-helix classifier. Let's briefly consider their features.

The volute feeder ensures the rise of the pulp from the bottom mark to the axis of the ball mill drum. Sands and additional water in the form of pulp enter the inlet from the sand chute of the mechanical single-spiral classifier. The pulp captured by two curls enters the drum of the ball mill in doses. In the intake device of the scroll feeder, it is possible to measure the pressure and pulp level, and by their values to evaluate the solid/water ratio in the pulp. However, this can be done only at sufficiently high costs of sands. In this cycle, the consumption of sands is relatively small, so such measurements cannot be carried out. With this in mind, it can be argued that in this technological cycle, the volute feeder performs the functions of a vehicle. Therefore, in this case, when controlling the grinding-classification of ores, the snail feeder does not play a big role and can be excluded from further consideration.

The electric drive of the ball mill drives the drum with the ball charge, ore and water into rotation. It is built on a synchronous AC motor and ensures the invariability of revolutions n per unit time. The electrical parameters of the electric drive are determined by the state of the drum. The decomposition of the ball mill electric drive assembly is shown in Fig. 7, which shows the input, output and perturbing effects. Among the initial parameters, we can distinguish the weighted average size of the solid d_{AS}, the consumption of solid Q_S, the consumption of the finished product Q_{FP} and the ratio of solid/water $K_{S/W}$. The disturbing factor is the active power P_w consumed by the electric motor of the mill. The active power P_w consumed by the ball mill electric drive at a constant drum rotation speed and a certain degree of filling it with balls φ is unchanged regardless of the amount of material fed per unit time. The productivity of the mill is proportional to the energy consumption for grinding, and it is determined by the degree of filling the drum with balls. The productivity of the mill increases up to φ=50%, then decreases with the growth of φ. The maximum power consumption and productivity of the mill is achieved at the drum rotation speed ψ=85% critical [2], which is the most advantageous. The above applies to the theoretical curve [2]. The experimental power consumption curve [2] corresponds to 40% filling of the drum with balls, which is maintained at a number of enterprises. Since both the theoretical and experimental extremes are on gentle dependences, in order to save balls at almost the same performance, it is more expedient to work with a somewhat smaller filling of the drum with balls. Passing through the point φ=40% also does not threaten anything, which is permissible with automatic control.

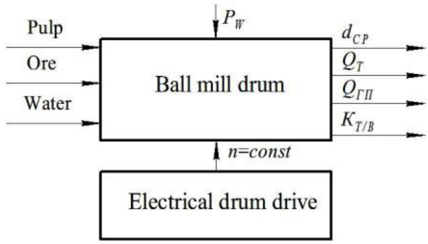

Fig.7. Decomposition of the electric drive unit of the ball mill drum

The balls and lining wear out during the operation of the ball mill, which reduces the degree of filling of the drum with grinding medium and, accordingly, the useful power consumption and productivity. At the same time, with a decrease in the degree of filling of the drum with balls, the distance of the center of gravity of the grinding medium from the axis of rotation increases, which, under the same conditions, increases the shoulder of the counteracting moment and, as a result, increases the amount of unproductive power consumed, which is spent unproductively. Therefore, under any conditions, the mill must be loaded with balls up to 40% of the drum filling. If the balls are reloaded once a day, then the productivity of the technological unit is reduced by 2%, and the power consumption is relatively large, corresponding to an increased productivity by 4%. Usually additional loading of balls is carried out in three days. Under such conditions, the productivity of the mills will decrease by 6%, and the electricity consumption will increase by 2%. This confirms the fact that the ball loading of the mill is practically an autonomous system and it needs to be given due attention. If the problems of ball loading are solved by a different approach, then the electric drive of the mill can be excluded from further consideration.

The electric drive of the spiral of a mechanical single-spiral classifier is designed for agitation of the pulp and transportation of sands to the sand chute. Therefore, the spiral forms a perturbing effect on the pulp, and the pulp on the spiral. Let us consider the perturbing effects that the pulp has on the spiral, which is fixed by its electric drive in the form of consumed active electric power. It is generally accepted that the main load on the spiral is made by the sands located between its turns in the upper part of the classifier. This is the basis for measuring the circulating load of the ore grinding-classification cycle. However, disturbing influences also act in the same direction. Among them, the following factors can be noted – the level and density of the pulp in the process unit, the amount of sand in its lower part, the temperature of the pulp, the peculiarity of the classifier bed, the wear of the working elements of the spiral and the decrease in its diameter, the condition of the working elements of the spiral, the state of the electric motor and gearbox. The analysis shows that the influence of these factors on the active power of the spiral electric drive is quite significant and it is impossible to determine the circulating load by its level within the accuracy requirements of the technological process. Therefore, the classifier spiral drive can be excluded from further consideration, assuming its rotation speed to be unchanged.

The last components of the decomposition of the grinding cycle of the ore classification, including the effect of the spiral on the pulp, must be considered in more detail, highlighting the perturbing factors, evaluating them and looking for ways to compensate or take them into account.

It follows from the considered that the decomposition of the ore grinding-classification cycle can be simplified and presented in the form of Fig.8. It can be seen from Fig. 8 that a ball mill can be represented by three components, and a mechanical single-spiral classifier by four. Let's consider these components in more detail.

Initial ore, pulp and water are supplied to the ball mill inlet to the initial part of the drum.

These dissimilar materials for effective grinding must be mixed qualitatively, the mixture should be averaged in terms of the content of components, usually performed by special devices – drum mixers.

However, given that the ball mill is an efficient mixer, these units are not installed in front of the ball mills. This, however, gives rise to negative consequences - the initial part of the drum acts as a stirrer, significantly reducing the performance of the ball mill.

Therefore, the task is to increase the efficiency of mixing and averaging in terms of the content of material components to ensure effective grinding of large solid inclusions in the ore.

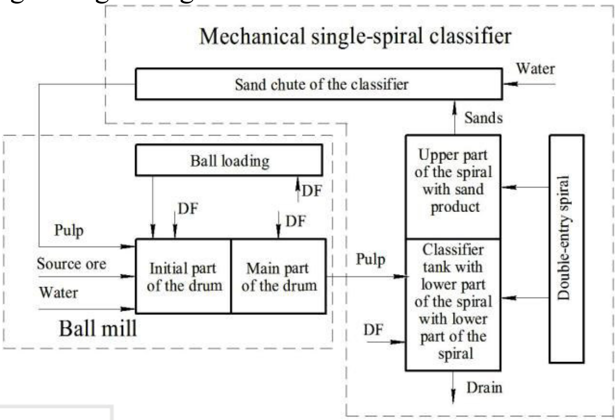

Fig. 8. Simplified grinding cycle decomposition – poor iron ores classification

To convert the sand product into pulp, additional water is supplied to the sand trough of the mechanical single-spiral classifier. The density of the pulp is determined by the productivity of unloading sands and the flow of water into the sand trough, which is usually taken unchanged. Mixing at the inlet of the initial part of the drum will be effective when the pulp from the sand product is maximally liquefied, and the original ore is moistened before entering the mill, supplying additional water to the ore entry zone. At the same time, it is advisable to divide the water that must be supplied to the ball mill into two streams - onto the surface of the ore for wetting and directly into the drum, into its initial part. An amount of water must be supplied to the surface of the ore, which will be proportional to the surface of the solid.

By modeling pulp liquefaction in a sand trough of a mechanical single-spiral classifier at a constant water flow, it was found that the density of the pulp changes with a period of 10s in accordance with a dependence close to harmonic [13]. For example, at average values of the circulating load and an average pulp density of 2 kg/dm^3, the maximum and minimum of the indicator are 2,5 and 1,3 kg/dm^3, respectively [13]. These are highly concentrated and watered zones of sand pulp, which reduce the efficiency of the balls. It is possible to correct the situation and significantly increase the efficiency of the balls by stabilizing the density of the pulp in the sand trough, i.e. γ_P=const. However, for this it is necessary to raise to a new, qualitatively higher level of measuring the circulating load in the grinding-classification cycle. Therefore, the system for automatic stabilization of pulp liquefaction in the sand trough of a mechanical single-spiral classifier is an autonomous system and can operate outside the entire cycle control system.

The specificity of the initial part of the drum is closely related to the ball loading. It is accepted in enrichment that large balls are located in the initial zone of the drum, and small balls are in the discharge of the ball mill. Consider how this affects the efficiency of ore grinding. At the beginning of the drum are the largest pieces of ore and the thinnest pulp, created from sands with additional water. The destruction mainly occurs between the surface of the lining and the balls, and the liquid pulp weakly fixes large pieces of ore in the massif. The probability of a large ball hitting an unfixed piece of ore is quite small. Therefore, the ore destruction efficiency is expected to be low. A completely different result is expected in this zone from the smallest balls in the mill feed. It is known that the power-to-weight ratio of small balls in an array is much higher compared to large ones. Small balls in the array in the process of moving to the lining easily pass liquid pulp through the holes, and large pieces of ore are retained. When they come into contact with the lining, large pieces of ore sandwiched in an array of small balls are effectively destroyed. Therefore, the ball load must be formed taking into account these features. Therefore, the initial part of the drum will perform its functions of material averaging and effective ore grinding and can be an independent autonomous ball mill system, which, however, is provided by autonomous control systems for water supply to the ball mill, automatic stabilization of pulp liquefaction in the sand trough of a mechanical single-spiral classifier and formation of a ball load at the input of the technological unit.

Ball loading is perhaps the main structural unit of the grinding cycle of the classification of low-grade iron ores. At present, a lot of a priori information on its improvement has been accumulated. With regard to the initial part of the drum, this is noted. In the discharge of a ball mill with small balls, large balls must be at the inlet. Here, the pulp is thick and viscous due to a decrease in the size of the solid. Small balls, neither alone nor in aggregates, can overcome such a viscous medium and grind the material. On the contrary, the viscous pulp flow will carry small balls out of the mill, reducing their required stay in the process unit and thereby increasing the consumption of ball material for grinding ore. Large balls will overcome the resistance of the viscous pulp, larger solid particles will be fixed on their surface and effectively crushed when the balls interact with each other, also the balls and the lining. Therefore, there is a prospect of improving the ball load of the mill, but all this must be proven.

Now in Ukraine there is an opportunity to switch to the use of balls of the 5th hardness group. The effectiveness of their use has been scientifically proven. It is necessary to make the transition to a multi-dimensional spherical load, however, this requires effective approaches to the development of its particle size characteristics and a criterion for assessing its approximation to the idealized characteristic.

To increase the efficiency of the balls can control the energy efficiency of the destruction of the ore directly in the drum of the ball mill, which have never been used. The development and use of such tools will be a significant contribution to the improvement of ball loading.

In the process of grinding the ore, the lining wears out and the ball loading changes the degree of filling of the drum, which worsens the performance of the mill. Currently, this is practically not taken into account. The solution of this problem will significantly improve the performance and energy performance of the mill.

A large number of factors influence the wear of balls, so for a long time there have been no significant changes in the issue of stabilizing the optimal ball load both in terms of the volume of the balls and in terms of their particle size. Many of these factors can be made unchanged during operation. Among them there is the property and fineness of the crushed ore. If the technological composition of the ore is not changed, then the influence of factors will become constant and then it will be easier to establish the wear of the balls and their corresponding introduction into the technological unit. A ball load will fully realize its functions when it is created optimal in composition and fineness, experimentally verified and will not change during operation. It, as an autonomous system, should be supported automatically. To do this, it is necessary to develop a theory for creating an optimal ball load and its automatic stabilization during operation.

In the main part of the ball mill drum, the process of grinding the ore to a predetermined size is carried out, depending on the size of the inclusions of the useful component. If the technological type of the ore will have unchanged properties, and the ball load will be optimal and stabilized, then the main disturbing effect will be a change in its size. The effect of changing the size of crushed ore occurs in the process of its unloading from cylindrical storage bins [14]. Crushed ore along the conveyor belt when unloading such bunkers is located in sections of considerable length - with fine ore, material of medium and largest size. Since the technological equipment of the crushing process, when using special bins, stabilizes its weighted average fineness, and it, adjusted to a certain largest fineness, will tend to increase in the process of wear of the working surfaces.

In the main part of the drum, the pulp density does not change at constant material consumption, the solid/water ratio also remains constant, and the viscosity increases from the beginning to the end of the drum. A change in pulp viscosity leads to a change in the speed of its movement along the drum, and, as a result, a change in the duration of ore grinding. This effect can be used to control the grinding process of a solid when its weighted average fineness changes. The weighted average size of the original ore can be estimated according to the proposed method [15]. It is possible to influence the speed of movement of the pulp in the drum with a predictive assessment of its viscosity at a certain final grinding size by setting and providing the required value of the solid/water ratio at the ball mill inlet. Thus, it is possible to provide the necessary grinding time of the ore, depending on its size at the mill inlet. Methods for evaluating pulp viscosity and the effect of pulp viscosity on its velocity need to be developed for the first time.

However, secondary disturbing factors will also act in the main part of the drum, which will also negatively affect the ore grinding process - this is lining wear and possible slippage of the ball load relative to the drum surface. In this case, the grinding of ore will be somewhat worse. This fact has never been taken into account, but it can have a significant effect on the grinding process and it is desirable to take it into account in this work.

A mechanical single-spiral classifier separates the material ground in a ball mill rather inefficiently. This negatively affects the performance of the ore grinding-classification cycle. Therefore, it is necessary to study its selected components in more detail. The classifier sand trough as an independent autonomous system has already been considered. It is necessary to maintain the density of the pulp at a given level.

The upper part of the sand helix was not explored far enough, as the circulating load of the cycle was measured almost outside of it. As already proven, the approaches used do not allow the determination of the circulating load with the accuracy required by the technological process as a result of the action of pulsating flow effects or other similar factors. Attempts to calculate the volume of sand between two turns of the spiral also did not lead to an increase in the accuracy of measuring the circulating load. Then this line of research was continued. At the first stage of the theoretical study of estimating the volume of sands between two turns of the helix of a mechanical single-helix classifier, a measurable parameter associated with the amount of material was found. This parameter turned out to be the height of the sands in the interturn space of the spiral, measured along the vertical passing through the lowest point of contact of the cylindrical bed and the edge of the feed turn. The analysis showed that it is possible to decompose the material between the turns of the spiral, representing it with two geometric figures – a part of a cylinder cut at an acute angle (lower part) and a cut pyramid (upper part). Their volume can be determined by exact analytical dependencies. These bodies are connected in the same horizontal plane. That is, where the lower part of the sands ends, their upper part begins there. These studies resulted in two papers [16, 17], which improved the previous solutions to this problem. In [18], a mathematical modeling technique was developed for the method of determining the total volume of sands according to the data of two geometric figures. The result of such modeling was the dependencies shown in Fig.9. Figure 9 shows that dependence 1 for the upper part of the sands is almost linear. Dependence 2 for the lower part of the sands is non-linear. However, the non-linear dependence belongs to the range of 0...15

cm, corresponding to small values of the circulating load, which are not used in practice. Therefore, the overall dependence, taking into account the linear parts 2 and 3, which characterizes the upper part of the sands, is almost linear. The considered dependences 2 and 3 are described by simple analytical expressions and therefore differ in accuracy. This solution is devoid of the disadvantages that are inherent in the preliminary developments for this purpose, however, as the analysis showed, it does not allow determining the instantaneous values of the material consumption during its unloading through the sand threshold, although the total volume is determined quite accurately due to the absence of pulsations. So, the initial parameter itself - the height of the sands - is an effective solution, and its use in this approach does not allow solving the problem of stabilizing the liquefaction of the pulp in the sand trough. Therefore, the proposed approach requires further improvement that needs to be implemented. The implementation should be directed in the direction of determining the amount of material that passes through the threshold of the classifier in time. Then, in accordance with it, a certain proportion of water can be supplied to ensure that the density of the pulp in the sand trough remains unchanged.

The two-lead spiral is an independent component of the mechanical single-spiral classifier. In the upper part of the classifier, it performs the usual functions of transporting sands. In the lower part, these functions are more complex, since it interacts with the pulp, where the separation of the solid by size occurs. In a mechanical single-spiral classifier, the separation of solids by size occurs according to the rate of fall of solid grains. On the one hand, gravitational forces of gravity act on solid particles, and on the other hand, the influence of a spiral in the opposite direction. Therefore, smaller solid particles cannot settle to the bottom and are taken out into the drain, while larger ones settle and fall into the sands. The operation of the helix has not been analytically described, so this separation is not clear. To improve the separation of solids by size, one should mathematically describe the operation of the spiral and consider the fall of solid particles in water under conditions of their high concentration [19]. When creating a theory of a spiral to control the process, one should determine the duration of the updraft, its speed, the length of the conditional path traveled, the time of free fall of solid particles, etc. In the theory of controlling the separation of solids according to a given grain size, it is necessary to substantiate the parameter or criterion for separation, which would be automatically provided.

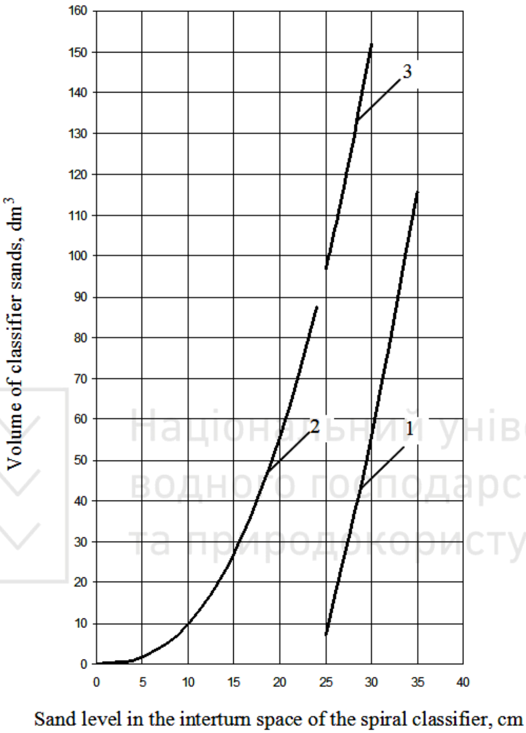

Fig. 9. The dependence of the volume of sands in the interturn space of the spiral of a mechanical single-spiral classifier on their level: *1* - 25-35 см; *2* - 0-24 см; *3* - 0-30 см

It is necessary to pay attention to the conditions for separating the solid by size from the point of view of the interaction of the spiral and the falling solid. Along the diameter, the spiral will have variable inclinations in the space where the working elements are located, which will affect the parameters of the upward flow under constant conditions of falling solid. In addition, the height of the bed of sands in the classifier will change according to the radius of the spiral, which leads to a change in the pulp level in the basin of the process unit. A lower level value affects the mechanism of throwing large fractions into the upper part of the basin. It is desirable to eliminate such a shortcoming in the classifier. Another factor is the influence of the spiral dynamics on the level of classifier drain. Along the spiral axis, the pulp level has an approximate value to the nominal value. From the side of the entry of the spiral, the level of the pulp decreases somewhat, and at its exit it rises with the casting of large solid fractions. This negatively affects the process of hard separation and the results of these factors must either be eliminated or reduced.

6. Conclusions

The conducted studies of the methodology for implementing energy-efficient invariant control of grinding-classification of ores based on indirect predictive estimates of the characteristics of raw materials and equipment allow us to draw the following conclusions:

1. The analysis showed that the system of rules and techniques for studying the object and subject of research, functions, principles, scope of methods and the formulation of the research goal make it possible to solve almost any technical problem using the existing specific methodology, including the implementation of energy-efficient invariant control of grinding-classification of ores based on indirect predictive assessments of the characteristics of raw materials and equipment.

2. In the technical sciences, general scientific research methods are mainly used, which are represented by methods of empirical, theoretical and general logical research.

The empirical and theoretical levels cannot be separated from each other, although they have a certain autonomy. It should be borne in mind that the experiment is the basis for the formation of hypotheses and theories, serves as a criterion for the truth of the theoretical results of research, but the determining side of the experiment is always theory.

Theoretical is the highest level of scientific research. General scientific methods in technical sciences are the most common - these are analysis and synthesis, abstraction, idealization, generalization, induction, deduction, analogy, modeling, system analysis, statistical methods. In fact, all these methods should be used in solving this problem, but the methods of analysis and synthesis, idealization in theoretical studies, the method of analogy in the development of mathematical models of actions and equipment, statistical methods in the processing of experimental data, determining the errors of information tools and control systems, are more widely implemented. proof of the adequacy of models to real processes.

3. Methods of empirical research - experiment, comparison, description, measurement (estimation) occupy an important place in the implementation of the methodology of energy-efficient invariant control of grinding-classification of ores.

The description method must be used almost continuously in the work. It has been established that the experiments should cover ten processes, means and systems of automation and a cycle of grinding the classification of ores. As shown, the comparison method in solving this problem should cover almost all the nodes of the complex: ball loading, lining wear, classifier bath, the volume of sand between the turns of the classifier spiral, the classifier sand trough, the information transmission channel, the movement of the pulp along the mill drum and the energy efficiency of grinding ore in ball mill. It is shown that, in addition to experimental studies, measurements (estimation) must also be applied in the automatic control of objects.

The analysis showed that during the transition to a qualitatively higher level of control and the implementation of energy-efficient invariant control of the grinding-classification of ores, it is necessary to develop a new method for measuring (estimating) technological parameters. These characteristics have never actually been evaluated operationally.

4. The multiplicity of technical sciences has given rise to a wide variety of special research methods. The science of "automation of control processes" includes methods of the theory of automatic control and its individual parts. In the problem under consideration, first of all, it is necessary to single out invariance methods, methods of adaptive systems, optimal systems, servo systems, stabilization of operating modes of technical systems, statistical dynamics of control systems, spectral theory of signals, signal filtering theory, algorithmic method, superposition method.

Auxiliary methods will also find their application - methods of the theory of random processes, measurement errors, information tools, sensitivity, approximation of dependencies. Among the general special methods, the decomposition method, the theory of systems, the theory of experiments, and the hydraulics of non-Newtonian fluids will be applied in the first place. Among the special methods of these studies, the central place is undoubtedly occupied by methods of the theory of automatic control, and then - methods of radio engineering systems and improving the accuracy of information means, among which preference should be given to their own approaches related to the features of their design, operation and implementation principle.

5. It follows from the foregoing that the considered methods of cognition, including a number of general scientific and special, as well as the proposed own methods (more than 20), can solve the vast majority of general issues of implementing energy-efficient invariant control of grinding-classification of ores, which increases the accuracy of estimating technological parameters and, as a result, provides quality indicators. control processes within the technological requirements.

6. It is shown that a ball mill can be represented by the initial and main parts of the drum and a ball load, and a mechanical single-spiral classifier can be represented by a two-way spiral, the upper part of the spiral with a sand product and a sand chute, a classifier basin with the lower part of the spiral and a drain threshold, which are independent autonomous systems, where the processes run independently and practically do not affect each other, which will allow the use of independent automatic control systems and the ability to take into account additional useful links between controlled processes, which will lead to a further improvement in the quality of the system complex.

7. The prospect for further developments in this scientific direction is the development of a complex of systems for energy-efficient invariant control of grinding-classification of ores using this methodology based on indirect predictive estimates of the characteristics of raw materials and equipment at the first stages of ore preparation at processing plants.

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INNOVATIVE TECHNOLOGY FOR OBTAINING FINE-GRAIN AND POWDER MATERIAL

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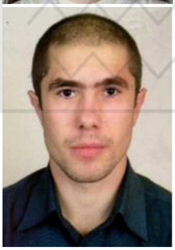

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Abstract

The production of fine-grained materials is associated with a high consumption of electricity and is mainly carried out in several stages of processing. The last stage - grinding is the most expensive. This necessitates the creation of new economical machines and technologies. A large amount of research carried out at the Dnipro University of Technology made it possible for the first time to substantiate the possibility of using a vibrating jaw crusher with a vertically located chamber and a pendulum suspension of the jaws as an independent grinding unit for the production of powder materials, as well as in production processes requiring special technological modes. The development of this direction is the creation of a vibroimpact grinder with an inclined working chamber, which provides regulation of the magnitude of the force effect on the material over a wide range. The purpose of the work is to substantiate the need for research and development of new design solutions for vibrating jaw crusher units, modular installations of a production line based on small-sized vibration equipment. The paper indicates the reason for the relatively low productivity of the vibrating jaw crusher and recommends ways to improve it. The possibility of redistributing the percentage of narrow classes of material in the finished product by changing the vibration frequency of the crushing jaws is shown. The analysis carried out shows the possibility of a significant increase in the efficiency of grinding materials in the development of new design solutions for the parallel zone. The features of the developed new class of vibrating jaw crushers with a complex jaw movement, which ensures the process of grinding the material along the entire length of the working chamber, are considered. The creation by a separate module of an innovative technological line for the production of fine-grained and powder materials with a horizontal layout of small-sized vibration equipment is justified.

Introduction

At present, along with large-capacity production, the number of enterprises is increasing, the need for which to obtain fine-grained and powder materials is limited from several tons to tens of kilograms per hour.

This necessitates the creation of highly efficient small-sized installations that provide a complete technological process for the processing of minerals, including the preparation of the starting material, the crushing and grinding operation, and the separation of the commercial product. In this process chain, the crushing and grinding operation is the most expensive due to the consumption of a significant amount of electricity [1], the high cost of repairs, and the replacement of rapidly wearing elements of crushing parts. One of the reasons is the use by enterprises of obsolete equipment with a low degree of crushing and a multi-stage technological process.

A large amount of research carried out at the Dnipro University of Technology made it possible for the first time to substantiate the possibility of using a vibrating jaw crusher with a vertically located chamber and a pendulum suspension of the jaws as an independent grinding unit for obtaining powder materials, as well as in production processes, requiring special technological regimes [2,3].

The design scheme of the vibrating jaw crusher in general (fig. 1) is an oscillatory system in which the jaws 1, movably articulated with the body 2 through the axes of the suspension 3, reported high-frequency vibrations. The rotary oscillatory movement of the jaws, as well as the vertical movement of the body, are generated by the forces of inertia of the rotating unbalanced masses of single-shaft vibration exciters 4.

The inertial principle of the action of the vibration exciter on the crushing jaws allows to ensure the normal operation of the crusher with direct contact of the working surfaces of the jaws at the moment of their closest approach, which is the determining factor in the use of the crusher as an independent crushing unit.

The high-frequency impact nature of loading of the material implemented in them made it possible to reduce the energy consumption and metal consumption of the installation, and to increase the degree of crushing [4].

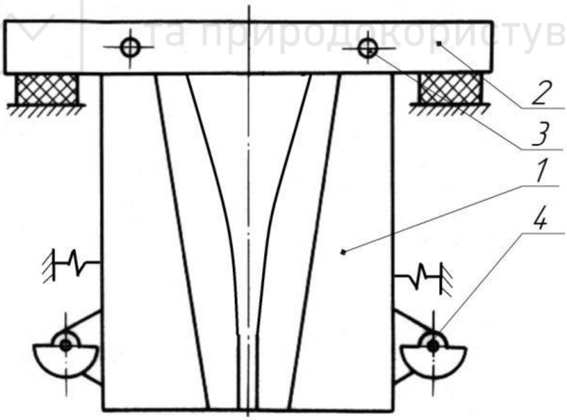

Fig. 1. Structural scheme of a vibrating jaw crusher with a vertical crushing chamber: *1* - jaw; *2* - body; *3* - suspension axis; *4* - vibration exciter

Table 1 shows the characteristics of the crushers parameters: PALLA type vibrating mill, ball drum mill with continuous screening and vibrating jaw crusher.

Table 1

Comparative characteristics of grinder parameters

Options	Chopper type				
	PALLA 20U	PALLA 35U	Drum mill	VSHCHD -220	VSHCHD - 220
Size of the original pro-duct, mm	0-5	0-5	0-50	0-50	0-50
Final product size, mm	0-0,2	0-0,2	0-0,2	0-0,2	0-0,2
Material for recycling	Medium hard	Medium hard	Ferro-chrome	Ferro-chrome	Ferro-silicium
Finished product capacity Q, т/ч	0,05	0,65	0,06	0,24	0,6
Installation weight, kg	600	2900	1845	600	600
Specific electricity consumption, W/Q, kWh/t	80	28,5	55	32	13,5
Grinding degree	15	15	65	65	65
Dimensions, mm	-	-	1245	580	580
	-	-	1320	720	720
	-	-	2255	1040	1040
Efficiency Qi, t/h	0,75	9,8	3,99	16	40
Electricity consumption related to efficiency W/Qi, kWh/t	5,35	1,86	0,78	0,48	0,2

The vibro-impact method of grinding material was further developed in the development of a new crusher design with an inclined crushing chamber, which provides control over the magnitude of the force effect on the material over a wide range [5].

In general, the crusher (see Fig. 2) includes a lower crushing jaw 1 mounted on the shock absorber 5.

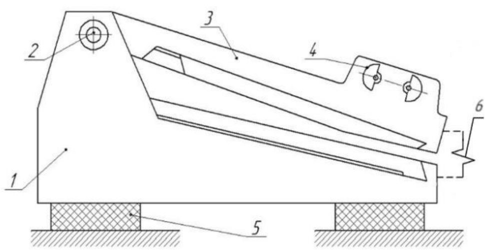

Fig. 2. Structural scheme of a vibratory jaw crusher with an inclined crushing chamber: *1* - lower jaw; *2* - jaw suspension axis; *3* - upper jaw; *4* - vibration exciter; *5* - shock absorber; *6* - elastic element

The upper jaw 3 is installed in the racks of the lower cheek by means of the suspension axis 2 relative to which it can perform rotational vibrations. In a given neutral position, the upper jaw is held by elastic elements 6. The vibrations of the jaws are generated by a two-shaft inertial vibration exciter 4.

The operation of vibratory crushers has shown that there are a number of units and elements, the improvement of which will increase the efficiency of the technological process. The purpose of the work is to substantiate the need for research and development of new design solutions for vibrating jaw crusher units, modular installations of a production line based on small-sized vibration equipment.

The productivity of the crusher in obtaining a fine-grained and powder product is one of its main disadvantages and requires a significant increase. This is mainly due to the small width of the unloading gap and the small volume of the prism of the unloaded material. One of the simplest ways to increase productivity in the required size class is to change the vibration frequency of the jaws [4].

For example, Fig. 3 shows the results of ferrosilicon crushing on the VSHD-220 crusher (here 220 is the jaw width).

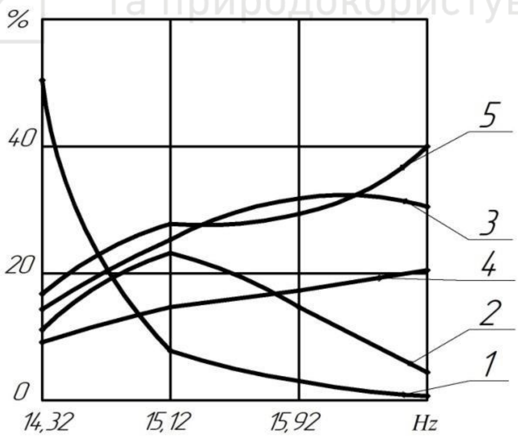

Fig. 3. Dependence of the output of crushed ferrosilicon on the vibration frequency of the jawsб mm: *1* - class + 5; *2* - class 3-5; *3* - class 1 - 3; *4* - class - 0,28 - 1; *5* - class -0,28

Pieces of 40-50 mm were taken as the starting material. The width of the unloading gap was 2 mm. The material was fed into the crusher by a vibrating feeder with a capacity of 1200 kg/h. If we take a fraction of -0,28 mm as a finished product, then at a frequency of 90 rad/s, the productivity will be 216 kg/h, but at a frequency of 110 rad/s, the productivity will reach 480 kg/h. The nature of curve 5 (see Fig. 3) predetermines, with a subsequent increase in the frequency of oscillation of the jaws, a sharp increase in productivity for a given fineness class, however, there are already difficulties with the strength and reliability of the construction and its elements.

It seems natural to increase the length of the discharge gap, but this parameter has its limitations and depends on the overall layout of the crusher.

A significant increase in productivity is achieved by creating devices that ensure the removal of the finished product from the working chamber as it is formed. One of the design schemes [6] of this type of vibratory crushers is shown in Fig. 4.

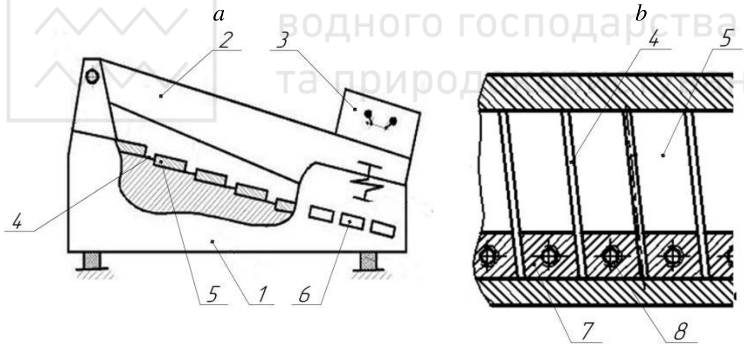

Fig. 4. Crusher with discharge gaps: *a* - general view, *b* - working surface of the lower jaw, 1 - lower jaw; 2 - upper jaw; *3* - vibration exciter; *4* - gaps; *5* - lining plate; *6* - unloading window; 7 - wedges; *8* - tightening bolts

The process of removing the finished product is as follows. The material entering the crushing chamber moves to the unloading slot of the crusher along the working surface of the lower jaw 1 and is subjected to high-frequency shock loading from the upper jaw 2, which oscillates under the action of the vibration exciter 3.

The interaction of a piece of material with the upper jaw leads to the appearance of material fractions of the required size. This class of material falls under the action of gravitational forces on the working surface of the lower jaw and, moving along with large pieces in the direction of the crusher discharge slot, enters the gaps 4. The width of the gaps is taken equal to the maximum fineness of the finished product and is set by the appropriate setting of the lining plates 5. The minimum gap width can be fractions of a millimeter. The lining plates are placed on the massive surface of the lower jaw and are fixed by tightening the wedges 7 by means of the bolts 8. The finished product, which has fallen into the gaps, moves along the inclined surface to the unloading windows 6. The stepped arrangement of lining plates along the length of the crushing chamber contributes to the loosening of the material in the process of its transition from the upper stage to the lower one, which also increases the efficiency of removing finished fractions from the crushing zone.

Parallel zone. In jaw crushers, the particle size distribution of the crushed product is determined by the size of the dropping material prism and may have a significant amount of excess grains. The reduction is achieved by installing lining plates with a parallel zone in the unloading window. The height of the parallel zone is taken from the condition under which the time of passage of the zone by a piece of crushed material is greater than the time of one revolution of the eccentric shaft. When this condition is met, each piece, at least once, will be clamped in a parallel zone during the unloading of the material. With the width of the unloading window, which is determined by tens of millimeters, there are no special requirements for the manufacture and installation of lining plates, which practically perform the function of a calibrator for the upper size of the crushed product.

A feature of the design of vibro-jaw crushers for obtaining fine-grained and powder material is the obligatory presence of a parallel zone. In this section of the crushing chamber, the formation of a qualitative composition of the finished product is mainly carried out.

Fig. 5 shows the results of crushing the sinter charge with an initial size of 3-15 mm. [7]. The height of the parallel zone was 25 mm (solid line) and 50 mm (dashed line).

An analysis of the granulometric composition of the crushed product shows that the height of the parallel zone is one of the control parameters that allows you to adjust the composition of the crushed product, redistributing its content in narrow size classes. For example, with a jaw oscillation frequency of 115 rad/s, by changing the height of the parallel zone, you can get 40% or 50% of a product of the -0,56 mm class.

The graphical dependence shows the presence of the boundary value of the height of the parallel zone, at which an increase in the vibration frequency of the jaws has practically no effect on the granulometric composition of the crushed product. So, in particular, for a height of 25 mm. it is not advisable to take the operating frequency of vibrations of the jaws more than 120 rad/s.

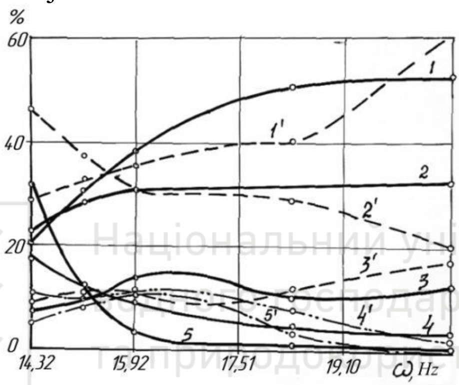

Fig. 5. The influence of the height of the parallel zone on the granulometric composition of the crushed product: 1 class-0,56 mm; 2 class 1-2 mm; 3 class 0,56-1 mm; 4 class 2-3 mm; 5 class +3 mm

Upon receipt of fine-grained and powder materials in a parallel zone, final grinding is carried out in a layer whose thickness depends on the strength of the material and can be only a few millimeters.

In connection with this feature, for the effective operation of the parallel zone, the initial setting of the parallelism of the working surfaces of the jaws is essential.

Several options are possible:

- parallelism is established with closed jaws;
- parallelism is established when the jaws are in the equilibrium position;
- parallelism is established at the maximum width of the unloading slot.

The first option is not rational, since when the jaw is retracted, a reverse grip angle is formed, which is also preserved when interacting with the material layer in any position of the jaw.

Setting at the maximum slot width ensures parallelism only at the time of loading. The material compression process takes place with a right grip angle, which reduces the grinding effect at the beginning of the parallel zone, especially at the minimum layer thickness. It is advisable to establish parallelism in the position of balance of the jaws , which ensures the force loading of the material over the entire surface of the parallel zone at the moment of the highest speed of the cheek. Parallelism must be maintained when adjusting the width of the unloading slot and the height of the parallel zone. This is achieved by constructive solutions, examples of which are shown in Fig. 6 [8].

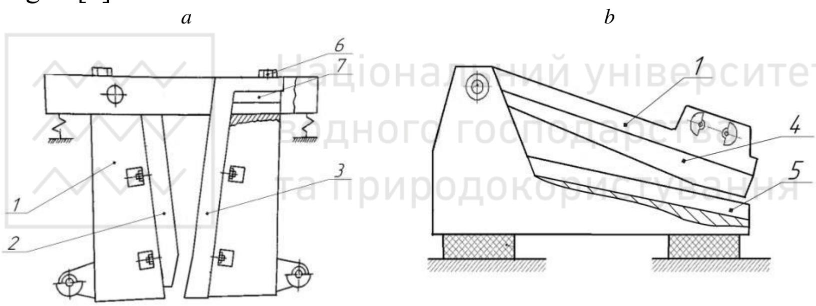

Fig. 6. Devices for regulating the parallel zone and the width of the unloading slot: *a* - vertical chamber; *b* - inclined camera; *1* - jaw; *2*,*3*,*4*,*5* - movable plates; 6 - attachment point; *7* – plates

Parameter adjustment is performed as follows. With a rigidly fixed plate 2 (see Fig. 6*a*), the maximum height of the parallel zone will be when the end surface of the plate 3 is located at or below the end surface of the plate 2. The required height of the parallel zone is set by shifting the plate 3 upwards and fixing it with a set of plates 7. After that, a rigid screed is performed plates with a cheek by means of the fastening unit 6. Similarly, the height of the parallel zone is adjusted in the crusher with an inclined crushing chamber. Plate 5 is in a rigidly fixed state (see Fig. 6*b*), plate 4 is installed with subsequent fixation in the position required by the technological regulations.

Adjustment of the width of the unloading slot while maintaining the height of the parallel zone is carried out by simultaneously shifting two plates (2-3, 4-5, Fig. 6). The joint adjustment of the slot width and the height of the parallel zone is carried out by shifting the plate 2 with a vertical location of the crushing chamber and plate 5 with an inclined location of the crushing chamber.

The analysis carried out shows the possibility of increasing the efficiency of grinding materials in the development of new design solutions for the parallel zone.

Crusher with complex jaw movement. A common disadvantage of jaw crushers with a pendulum jaw suspension is the absence of a linear jaw oscillation amplitude in the region of the suspension axis. This leads to a shift from the jaw suspension axis of the initial breaking load on the material, an increase in the length of the crushing chamber, dimensions and metal consumption of the crusher.

Developed in Dnipro University of Technology a new class of vibrating jaw crushers with a complex jaw movement [9] provides the process of grinding the material along the entire length of the working chamber (see Fig. 7).

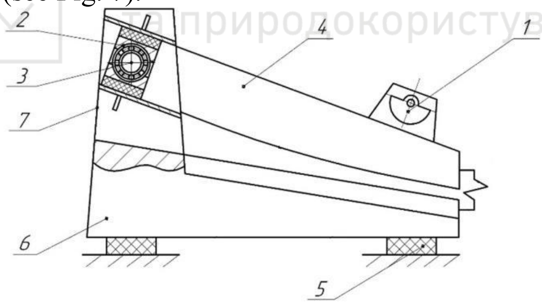

Fig.7. Crusher with a complex movement of the jaw:
1 - vibration exciter; *2* - bearing support; *3* - suspension axis; *4* - upper jaw; *5* - elastic elements; *6* - lower jaw; *7* - receiving window

A feature of the crusher is the use of a single-shaft inertial vibration exciter 1, which generates a disturbing force with a rotating vector and the installation of bearing supports 2 suspension axes 3 of the upper jaws 4 in the elastic elements 5, which makes it possible for the suspension axis to move relative to the lower jaw 6 in any direction considered in the plane of the drawing . The amount of movement of the suspension axis is determined by the rigidity of the elastic elements, which is much greater in the direction perpendicular to the working surface of the upper jaw than in the longitudinal direction. This proportionality forms the trajectory of the upper jaw in the form of an ellipse with the direction of the major axis along the working surface of the upper jaw. Under the action of the disturbing force of a single-shaft inertial vibration exciter, the upper and lower jaws oscillate. Due to the difference in masses, the amplitude of oscillations of the upper jaw is higher than the amplitude of vibrations of the lower jaw. The source material entering the receiving window 7 of the crusher moves to the discharge slot along the lower cheek and, at the moment of contact with the working surface of the upper jaw, is subjected to high-frequency force loading. At the same time, a new technological process (principle) of the interaction of the upper jaw with the material is implemented. In the region of the cheek suspension axis, where the magnitude of the amplitude of the rotational oscillations of the jaw is insufficient to create compressive destructive deformations in the piece of material, the destruction of the piece of material is carried out by means of shear deformations created by the displacement of the upper jaw.

With further movement of the piece and reaching the area where the amplitude of the rotational vibrations of the jaw is sufficient to create a destructive compression deformation in the piece, a different character of the interaction of the upper jaw with the material takes place, in which the material receives a combined force loading according to the principle "compression + shear", which significantly increases the efficiency of the grinding process.

The innovative technological line for the production of fine-grained and powder materials is represented by a set of units that provide preliminary drying of the source material, crushing and grinding operation and isolation of the finished product.

The creation of a vibrating jaw crusher with an inclined crushing chamber allows you to move from the traditional vertical layout of equipment to its horizontal placement (see Fig. 8), which greatly simplifies installation and maintenance, significantly reduces the material consumption of the line.

The production line works as follows.

From the hopper - feeder 1, the material is fed with a given capacity to the vibrating conveyor of the drying plant. Two types of vibroconveyor have been developed: for lumpy and bulk materials. A feature of the vibroconveyor for lumpy materials is the possibility of drying material with a wide granulometric composition, including grain fractions from fractions to tens of millimeters. The material supplied for drying, under the action of a directed vibration disturbance, moves along the lattice stepped surface and is blown through the slots with hot air [10]. Conveyor length up to 6m, capacity up to 5t/h.

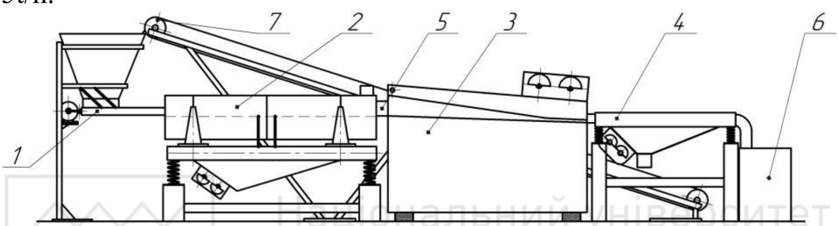

Fig. 8. Scheme of an innovative technological line for the production of fine-grained and powder materials: *1* - hopper - feeder; *2* - vibrating dryer; *3* - vibrating jaw crusher; *4* - screen; *5* - docking elements

A more compact design of the vibratory conveyor for bulk materials with a particle size of up to 15 mm. The created complex profile of the working surface made it possible to set the movement of the material with intensive mixing, which increased the drying efficiency and increased the time the material was under high-temperature exposure [11]. Tests of a laboratory sample of the vibroconveyor showed the possibility of reducing the length of the vibroconveyor, compared with the usual perforated profile of the working surface, by several times with the same technological indicators.

Not all materials require pre-drying. In its absence, the raw material is fed into the working chamber of the crusher directly from the feed hopper.

The vibratory crusher accepts material up to 100 mm in size and carries out its grinding to a micron condition. The separation of the finished product is carried out on a screen with a complex profile of the working surface. Reducing the dimensions of the destructive and classifying equipment in height makes it quite easy to organize a closed cycle with a minimum amount of transport equipment.

Conclusions

The innovative technology of grinding materials based on vibrating jaw crushers has great potential for further development for fine destruction of materials, including strong and abrasive ones.

The most significant way to increase the productivity of a vibrating jaw crusher when producing finely divided materials is to remove the finished product from the working chamber as it is formed.

The development of new solutions for creating a parallel zone is a great reserve for improving the efficiency of grinding in vibrating jaw crushers.

The created small-sized structures are the basis for the development of modular installations of technological lines: feeder - vibrating dryer - vibrating crusher - vibrating screen; feeder - vibro crusher - vibrating screen - conveyor for closing the grinding (crushing) cycle. The capacity of such modular plants is up to 5t/h, length up to 10 m.

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THE USE OF INJECTION ROCK BOLTS IN HE MINING AND GEOLOGICAL CONDITIONS OF UKRAINIAN COAL MINES

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Abstract

The article presents the results of simulation of coupled processes of rock deformation and liquid polymer filtration in the disturbed area around the mine working. The problem formulation takes into account the initial permeability of host rocks as well as the permeability due to the mine working driving, time of polymer delivery and hardening, and foaming effect of the polymeric composition in the process of mixing of its components. Certain changes in physicomechanical and filtration characteristics of rocks during the polymer hardening also were taken into account in the problem formulation as well as the fact that a metal delivery pipe

starts operating as a reinforcing element after hardening of the polymeric composition is over.

It was demonstrated that the location of rock bolts is important to form a rock-bolts arch. With sufficient density of injection rock bolts, the formed rock-bolts arch may serve as a barrier controlling both water inflow and gas emission from the undermined rocks into the mine working. Dependence of changes in the reinforced area upon the value of initial permeability of the host rocks was derived. If the values of initial permeability are low then size of the rock-bolt supports and their shape are determined using only a value of the unloaded zone around the mine working.

It was shown that steel and injection rock bolts complement each other very well, increasing the stability of the mine working and reducing the filtration permeability of the host rocks. Injection rock bolts exclude the possibility of destruction of host rocks and more effectively reduce the permeability of disturbed rocks in the zone of influence of the tectonic fault. And steel rock bolts better restrain the expansion of the zone of increased difference of the stress tensor components. Therefore, in the case of heavily watered rocks or a high probability of methane breakthroughs into the mine working, it is better to install injection rock bolts and deliver the polymer into the disturbed rock as close as possible to the mine face. Then a water- and gas-proof shell arch around the mine working will be created in the immediate vicinity of the mine face, which will make it possible to quickly prevent emergency water inflows and gas emissions. If there is no such threat and the priority is to maintain the long-term stability of the mine working, then first of all it is necessary to install steel rock bolts with polymer fixing in the borehole.

Key words: injection rock bolts, complicated mining and geological conditions, numerical simulation, supporting technology, mine workings.

1 Introduction

There are a large number of tectonic faults in the coal-bearing strata of the Western Donbass [1, 2]. These faults are surrounded by zones where rocks have a broken structure, reduced strength, are very crushed [3, 4]. Weak, unstable rocks are prone to soaking with subsequent loss of bearing capacity [5, 6]. The total thickness of watered rocks ranges from 20 m to 1660 m in the Western Donbas [7]. The gas content reaches 25 m^3/t in coal seams and 7 m^3/t in sandstones. Mine workings driving in highly fractured, unstable rocks is a serious problem. The high permeability of rocks in the zones of tectonic faults causes the possibility of methane breakthroughs and large water inflows into mine workings [8]. It is very difficult to choose supporting scheme for a mine working in such conditions.

Roof bolting is a spatial structure of steel bolts fixed in boreholes with a polymer fixer [9-11]. This support has significant advantages in all technical and economic indicators compared to traditional types of supporting. Roof bolting makes it possible to ensure the reliable and safe functioning of mine workings throughout the entire period of their maintenance, if the technology of bolts setting is observed [12-14]. However, if a mine working is driving in highly fractured, unstable rocks, additional means of supporting are needed to ensure its stability.

One of the solutions to the problem of mine workings support in highly fractured rocks is the use of injection rock bolts. An injection rock bolt is a metal seamless pipe with a sealer to deliver fortifying solution into the fractured rocks, Fig. 1. After delivery, the metal pipe is used as extra reinforcement facilitating high shear strength. Technical characteristics of IRMA injection rock bolts are given in Tab. 1 [15].

Fig. 1. An injection rock bolt with a sealer [15].

Table 1

Technical characteristics of IRMA injection rock bolts

Characteristic name	IRMA 40	IRMA 110	IRMA 200	IRMA 250
Breaking load, kN	40	110	178	229
Breaking elongation, %	–	–	>15	>15
Tensile strength, N/mm²	360	400	700	700
External diameter, mm	22	22	22	25
Internal diameter, mm	12	12	8	11

Generally, the delivered solution consists of two liquid components pumped separately through the hoses. Then, the components mix in a blender, and deliver under high pressure (6-9 MPa) to the rock mass by means of rock bolt system and a sealer. The density of the composition at 25°C is 1000-1500 kg/m^3, the viscosity at 15°C is 110-670 MPa·s. The reagent mixer is polymerized with 1,5-3,5 times increase in volume. Owing to high pressure, the foamed composition gets even in small fissures of the rock mass .

Injection rock bolts serve to strengthen the disturbed near-contour rock, increase the stability of mine workings, reduce the rock permeability, reduce gas and water inflows into a mine working [15-18]. But what rules should be followed when creating effective supporting schemes? To answer this question, it is necessary to study the mechanism of operation of the injection rock bolt, the principles of forming an impenetrable arch around the mine working, the features of the operation of injection and steel-polymer rock bolts and their interaction. Therefore, the purpose of this work is to develop a mathematical model for studying the mechanism of operation of the injection rock bolt and substantiating the conditions for the formation of a rock-bolts arch around a mine working, which ensures its stability and protects against water and gas inflows.

To achieve the goal, the following tasks were set:

- to develop a mathematical model of the coupled processes of rock deformation around the mine working and liquid polymer filtration in the disturbed area, taking into account changes in the strength and filtration properties of rock in the process of polymer solidification;
- to perform numerical simulation using the finite element method;
- to investigate the process of formation a reinforced support around one injection rock bolt;
- to investigate the formation of a reinforced, impermeable rock-bolts arch around the mine working with injection rock bolts;
- to determine the factors influencing the formation of the rock-bolts arch around the mine working, which ensures its stability and protects against water and gas inflows;
- to investigate the stability and effectiveness of the supporting of the mine working when using steel rock bolts in combination with injection rock bolts.

2 Methods

The coupled processes of rock deformation and liquid polymer filtration in the disturbed rock are described by a system of equations [19]

$$c_g \frac{\partial u_i}{\partial t} = \sigma_{ij,j} + X_i(t) + P_i(t)\,; \tag{1}$$

$$\frac{\partial p}{\partial t} = \frac{k}{\mu \cdot \beta \cdot m}\left(\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2}\right) + q(t)\,, \tag{2}$$

where c_g - damping ratio, kg/(c·m^3); u_i - displacements, m; t - time, s; $\sigma_{ij,j}$ - derivatives of the stress tensor components along x, y, Pa/m; $X_i(t)$ - projections of the external forces acting on the volume unit of solid body, N/m^3; $P_i(t)$ - projections of forces caused by liquid polymer pressure in the fracture space, N/m^3; p - liquid polymer pressure, Pa; k - permeability coefficient, D; μ - polymer viscosity, Pa·s; β - polymer compressibility factor, 1/Pa; m - rock porosity, %; $q(t)$ - foaming function, Pa/s.

The problem is solved in elastoplastic formulation. Mathematical description of rock transition into the disturbed state involves Mohr-Coulomb failure criterion.

The initial and boundary conditions for this task set

$$\sigma_{yy}\big|_{t=0} = \gamma H; \quad \sigma_{xx}\big|_{t=0} = \lambda\gamma H; \quad p\big|_{t=0} = 0.1\ \text{MPa}\,,$$

$$u_x\big|_{\Omega_1} = 0; \quad u_y\big|_{\Omega_2} = 0; \quad p\big|_{\Omega_3} = p_0; \quad p\big|_{\Omega_4} = 0.1\ \text{MPa}\,,$$

where λ - side thrust coefficient; γ - averaged weight of the overlying rocks, N/m^3; H - mining depth, m; p_0 - delivery pressure, MPa; Ω_1 - vertical outer boundaries; Ω_2 - horizontal outer boundaries; Ω_3 - filtering share of a borehole surface; Ω_4 - internal boundary (mine working).

Such geomechanical parameters as Q^*, characterizing the difference of the stress tensor components, and P^*, characterizing a probable rock failure mode, are applied to evaluate the stress state of rock [20]

$$Q^* = (\sigma_1 - \sigma_3)/\gamma H;$$

$$P^* = \sigma_3/\gamma H,$$

where σ_1, σ_3 - maximum and minimum components of the principal stress tensor, Pa.

As a result of mining, the initial stress field changes and crack systems are formed in the host rock. The technological permeability field k_{tech}, stimulated by the mining and dependent on the stress tensor components [21-24], is superimposed on the initial permeability field k_0

$$k = k_0 + k_{tech}\left(\sigma_{ij}\right).$$

The change in the values of the permeability coefficients depending on the components of the principal stress tensor can be described as follows [25]

$$k = k_0 + \begin{cases} 0, \;\; Q^* < 0,4; \; P^* > 0,2; \\ k_{\min}, \;\; 0,4 < Q^* < 0,6; \;\; P^* > 0,1; \\ e^{0,26Q^* - 4,65}, \;\; 0,6 < Q^* < 1,0; \;\; P^* > 0,1; \\ k_{\mathrm{fr}}, \;\; Q^* > 1,0; \;\; P^* < 0,1. \end{cases} \tag{3}$$

where $k_{\min}$ - the minimum permeability value required to start the filtration process, m^2; k_{fr} - permeability in the fractured zone, m^2.

The finite element method [26] was used to solve equations (1)-(3). Each time step *i*, which corresponds to approximately 5 minutes, takes into consideration the stress field influence on the filtration area shaping; influence of the liquid polymer pressure on the stress state of the rock [21]; and changes in physicomechanical as well as filtration characteristics of the rock during the polymer hardening.

Roof bolting is simulated with the help of rod finite elements [27].

3 Simulation of rock reinforcement when the polymer composition is injecting and hardening

Injection rock bolts are usually installed some time after the mine face has been removed for certain distance. For example, when the haulage crosscut was being built at the Heroiv Kosmosu mine in the zone of the Bogdanovsky Fault, polymeric chemical composition was injected into the mine roof and walls with a lag of 5 m from the mine face [17]. During this time, the near-contour rocks around the mine working are partially unloaded from rock pressure, acquiring additional permeability k_{tech}. Therefore, we will not simulate the injection process immediately, starting from the first time step *i*, but a little later, at the time $t=t_{\mathrm{start}}$. t_{inj}=20 min is the delivery period (4 time steps). The same time is necessary for complete hardening of the polymer. p_0=6 MPa is the delivery pressure.

Foaming (increase in volume) of the polymer composition during mixing of its components and chemical reactions is modeled using the source function $q(t)$ in the filtration equation for the liquid components of the polymer composition (2).

When the liquid polymer that fills the cracks and voids in the rock solidifies, the physical-mechanical and filtration properties of the hardened region change. In this study, it was assumed that while the polymer solidifies: the elasticity modulus of the hardened finite element increases linearly by 1.7 times; compressive resistance σ_c increases linearly by 1,5 times; ultimate tensile strength σ_p increases linearly by 2,0 times; the filtration permeability coefficient of the hardened finite element decreases linearly to 0.

A metal delivery pipe starts its operation as a reinforcing component only after durable fixation within a borehole, that is, after the polymer has solidified. Therefore, we will take into account the reinforcing effect of the rod finite elements, starting from the time $t=t_{start}+t_{inj}$.

The length of the injection rock bolt is 2,5 m. The sealer 0,26 m long is located at a distance of 0,7 m from the bolt head, Fig. 1.

4 Mechanism of forming a reinforced arch in the mine roof using injection rock bolts

4.1 Formation a reinforced support around one injection rock bolt

Let us consider a rectangular cross-section mine working with 5.2 m width and 3,0 m height being driven through the soft rocks (elasticity modulus is $E=10^4$ MPa; and compressive resistance is $\sigma_c=28$ MPa). To study the process of formation of a reinforced support around an injection rock bolt, we will consider the case when one injection rock bolt is installed in the mine roof. We will also assume that the host rocks are disturbed and have an initial permeability $k_0 = 0{,}01$ mD. We will start injection process simulation from the 2nd time step. The metal delivery pipe will start its operation as a reinforcing component only after durable fixation within a borehole, so the influence of rod finite elements will be taken into account starting from the time step $i = 6$.

Fig. 2 demonstrates the results of calculating Q^* parameter values, zones of inelastic deformations (red color) and permeability coefficients before installing the injection rock bolts and the start of polymer injection.

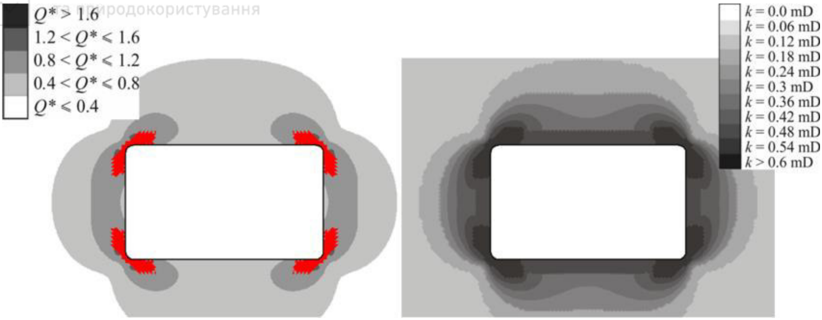

Fig. 2. Distributions of Q^* parameter values and inelastic deformation zones (left side); permeability coefficients (right side)

The mine working driving disturbs the equilibrium state of rocks; there is a redistribution of the initial stress field. By the time the injection rock bolt is installed, the near-contour rocks have been partially unloaded from rock pressure; a zone of increased diversity of components has been formed around the mine working (Fig. 2, left side). Under multicomponent loading, when microcracking occurs in the rock ($0{,}4 < Q^* < 0{,}6$), the increase in permeability is very insignificant. This stage of deformation is characterized by the accumulation of single, noninteracting defects [28]. Beyond the elastic limit, before reaching the strength limit ($0{,}6 < Q^* < 1{,}0$; $P^* > 0{,}1$), intense cracking and uncontrolled cracks growth occur. Deformations rapidly increase due to the propagation of cracks and loosening of the rock. When stresses reach the ultimate strength of the rock ($P^* < 0{,}1$), the process of macroscopic fracture begins. Brittle fracture of the rock is characterized by an increase in deformations, loosening and, accordingly, the volume of the material [28], which causes a sharp increase in permeability. Thus, the values of the permeability coefficients around the mine working increase (Fig. 2, right side).

After drilling a borehole, installing the injection rock bolt and starting the polymer delivery, the stress field noticeably changes, Fig. 3.

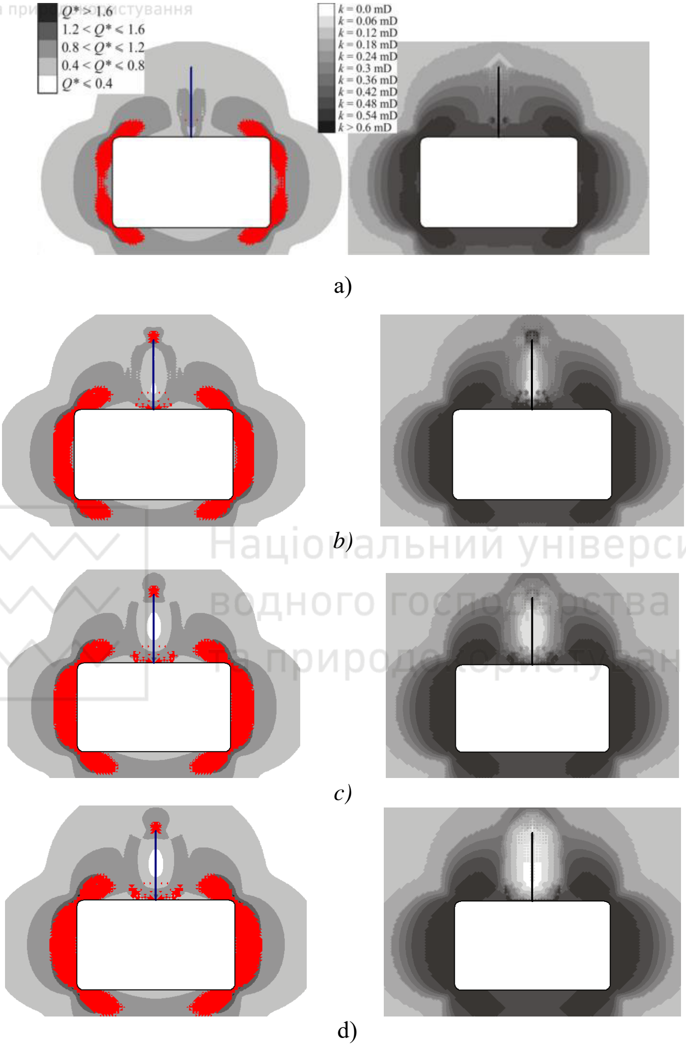

Fig. 3. Distributions of Q^* parameter values and inelastic eformation zones (left side); permeability coefficients (right side): *a* - $i = 4$; *b*- $i = 6$; *c* - $i = 8$; *d* - $i = 10$

The areas of increased difference of the stress tensor components (Q^* parameter) and inelastic deformations around the mine working grow over time, (Fig. 3, left side); the host rock continues to unload from rock pressure. However, at 10-15 minutes of polymer delivery, its effect on the rock stress state and permeability of near-contour rocks begins to show; at the place where the injection rock bolt was installed, in the mine roof, at *i*=4 the connected domain where $0{,}8<Q^{*}<1{,}2$ is broken.

In terms of *i*=6, a delivery process is over, and the polymer has hardened partially. A metal pipe starts operating as an rock bolt. Both elasticity modulus and strength limits of the polymer-reinforced rocks increase. Decrease in the difference of the stress tensor components and the rock permeability is the common result of such transformations. Q^{*} parameter values around the rock bolt reduce; now in this area $Q^{*}<0{,}8$ (Fig. 3*b*, left side). The values of permeability coefficients, although in a small volume of rock, drop to values less than k_0 (Fig. 3b, right side).

After another 2 time steps, at *i*=8 (Fig. 3*c*, left side), the area of reinforced rocks around the injection rock bolt expands, the diameter of the zone where $0{,}4<Q<0{,}8$ is 1,4 m. A zone of equal-component compression $Q^{*}<0{,}4$ with a diameter of 0,55 m appears. Accordingly, the volume of impermeable rocks around the injection rock bolt increases, which is clearly seen in Fig. 4*c*, right side. The diameter of the zone where $k<0{,}1$ is 1,1 m.

At *i*=10, the polymer completely solidified; the volume of impermeable rocks around the injection rock bolt increases even more. The diameter of the zone of reduced permeability now reaches 2,0 m.

Next, we will consider the change in the pressure of the polymer composition in the study area during its injection and solidification. To demonstrate the influence of the effect of an increase in the volume of the polymer during chemical reactions on the area of distribution of the reinforcing composition, the results of calculations, which were performed with and without foaming, are shown in Fig. 4.

The reinforcing composition is delivered through the permeable surface of the borehole; the pressure has maximum values there. A filtration process of a liquid polymer is restricted by the rock mass area with rather developed fracture network.

When the components of polymeric composition are being mixed, chemical reaction behaviour increases its volume. While increasing the volume, the polymer generates extra pressure inside a fractured space of the rock. Under pressure, the foamed composition gets even into small fractures of the rock.

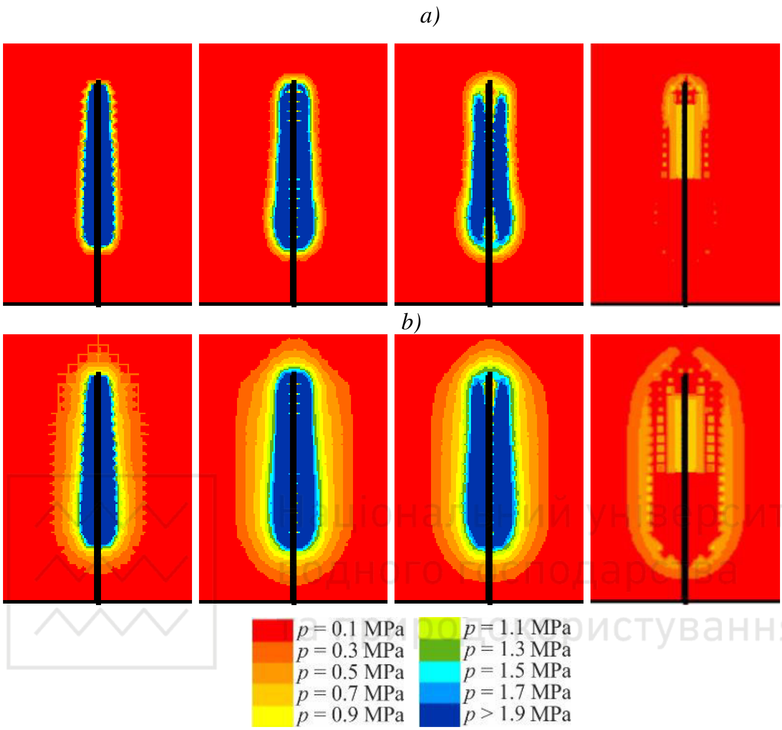

Fig. 4. The liquid polymer pressure at time steps *i*=4; *i*=6; *i*=8; *i*=10: *a* - ithout foaming of the polymer; *b* - taking into account its foaming

Therefore, the area of high pressure around the injection rock bolt is much larger when foaming is taken into account (Fig. 4*b*).

Starting from the 6th time step, delivery is completed, the polymer continues to solidify, and its pressure decreases.

Fig. 5 shows the rock region around the injection rock bolt, the fracture space of which is filled with polymer, at various points in time.

The calculations were performed without taking into account the polymer foaming and taking it into account polymer foaming. The diameter of the reinforced area in the first case is 1,25 m (Fig. 5*a*, *i*=10), in the second case it is 2,15 m (Fig. 5*b*, *i*=10).

a)

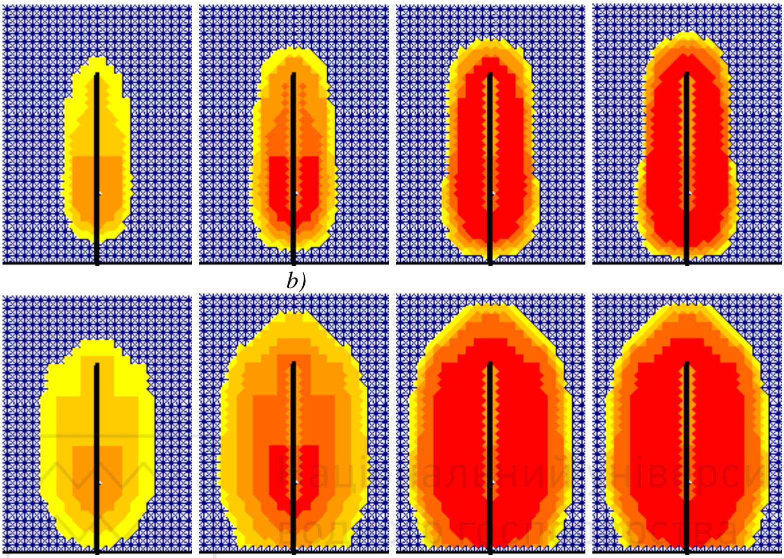

Fig. 5. Reinforced area around the injection rock bolt at time steps i=4; i=6; i=8; i=10: *a* - without taking into account the polymer foaming; *b* - taking into account polymer foaming

Thus, after the solidification of foamed polymer, a reinforced gas- and water-proof area is formed around the injection rock bolt. Its shape and dimensions depend upon the configuration and dimensions of a filtration zone being a permeable space in the neighbourhood of an injection rock bolt within which the liquid polymer spreads. Rock permeability in this zone is determined by natural fracture pattern as well as the technological one stipulated by an unloading degree of near-contour rocks.

4.2 Formation of a reinforced, impermeable rock-bolts arch in the mine roof with injection rock bolts

While developing a mine working support scheme using injection rock bolts, one should know how close is interaction of the reinforced zones and whether they form the integrated mechanical structure being a complete arch capable of protecting the mine working against failure, gas emission, and water inflows. If the reinforced zones are not interconnected then breakdown of the arch and roof failure are possible Let us study how the shape and dimensions of the polymer-reinforced area change depending on the density of injection rock bolts setting. We will consider a mine working, which is driving under conditions similar to those described above, and in the roof of which N_a injection rock bolts are installed:

- the first case, N_a=3, distance between bolts is 2 m;
- the second case, N_a=5, distance between bolts is 1,2 m.

The computations have helped obtain distributions of values of geomechanical and filtration parameters at various time steps if N_a=3 and N_a=5. Fig. 6 shows distributions of Q^* parameter values and nonelastic deformation zones (red colour). Fig. 7 demonstrates distributions of permeability coefficients *k* within the studied area during the polymer delivering and solidification.

In both cases, the areas of high difference of the stress tensor components and nonelastic deformations around the mine working extend in the course of time (Fig. 6); and rock mass releases gradually from rock pressure. However, a zone of high fracturing where $0,8<Q^*<1,2$ decreases within the mine working roof, in the bolted area (Fig. 6a). In such a way, strengthening influence on the stress state of near-contour rocks starts manifesting despite the injection rock bolts are still surrounded with a zone where $0,8<Q^*<1.2$ and roof rock permeability *k* have experienced minor changes (Fig. 7a).

In terms of *i*=6, a delivery process is over, and the polymer has hardened partially. A metal pipe starts operating as a rock bolt. Both elasticity modulus and strength limits of the polymer-reinforced rocks increase. As a result, there is a decrease in the difference of the stress tensor components and the rock permeability. Q^* parameter values around the injection rock bolts reduce. In terms of N_a=3, central bolt is surrounded with an area where $Q^*<0,8$. The same is true for three central bolts if N_a,=0,5 (Fig. 6*b*). The values of permeability coefficients *k* drop down the initial permeability coefficients k_0 (Fig. 7*b*) neutralizing changes caused by the mine working driving. If $N_{a,}$=5 then the greater rock amount is involved.

After the solidification process in terms of *i*=10 is over (Fig. 6*c*), the area of the reinforced rock around injection rock bolts expands; width of the zone where $0,4 < Q^* < 0,8$ and $N_a = 3$ is 1,7 m. If $N_a = 5$ then the width is 3,2 m. The area of uniform compression where $Q^* < 0,4$ arises around the central bolts. Since the moment, each injection rock bolt is surrounded with a zone of completely impermeable rocks with more than 0.6 m diameter shown clearly in Fig. 7*c*.

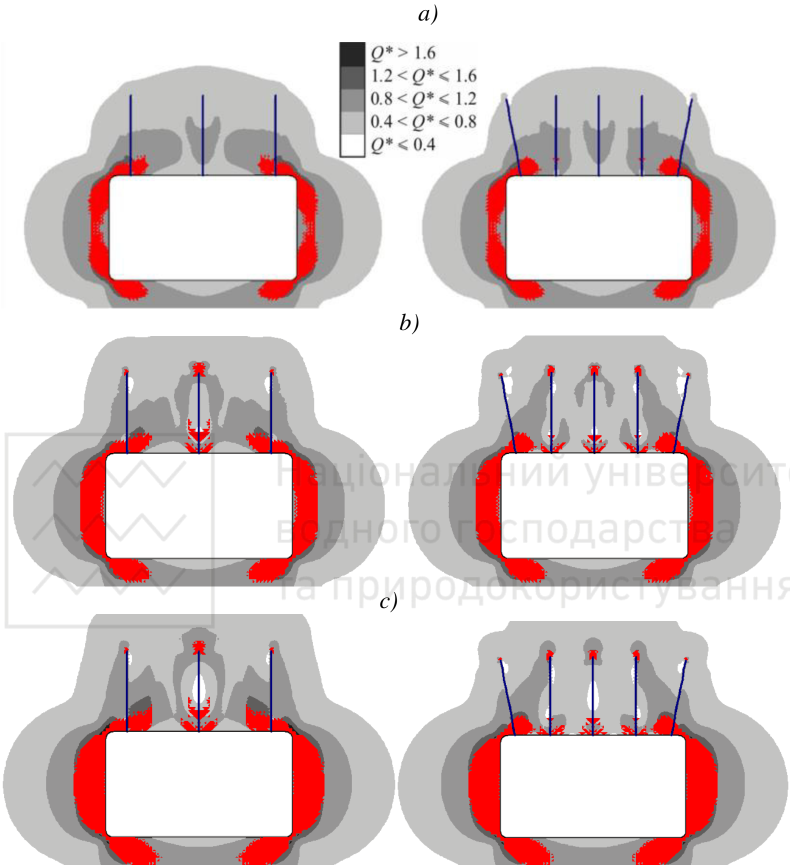

Fig. 6. Distribution of the Q^* parameter values and the inelastic deformation zone bolts are installed in the when 3 (left side) and 5 (right side) injection rock mine roof: *a* - = 4; *b* - *i* = 6; *c* - *i* = 10.

However, if $N_a = 3$ then highly permeable rocks (in our case, their permeability is more than 0,4 mD) occur between the impermeable areas. Three monolith polymer-reinforced rock-bolt supports are not linked; they are separated by zones of the fissured disturbed rocks where $0{,}4 < Q^* < 0{,}8$ and $k > 0{,}4$ mD.

In the second case when $N_a = 5$, almost impermeable rock-bolt arch is formed from five polymer-reinforced supports. Fig. 6 explains that the area with $Q^* < 0,8$ parameter values has spread towards the mine working walls occupying now greater share of the rock bolted mine roof. Owing to the increased value of minimum component of the principal stresses as well as the decreased maximum component, the stressed state of rocks went into uniform compression state and became stable. As a result, the system, consisting of five injection rock bolts, has formed the high-strength uniform arch blocking the potential for spontaneous failure.

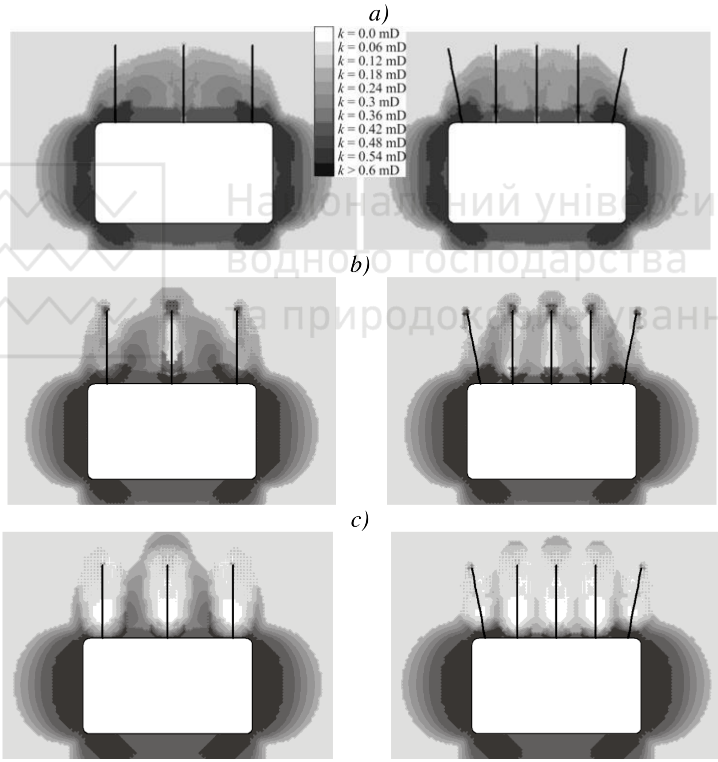

Fig. 7. Distribution of permeability coefficients values when 3 (left side) and 5 (right side) injection rock bolts are installed in the mine roof: *a* - $i = 4$; *b* - $i = 6$; *c* - $i = 10$

Fig. 8 and 9 demonstrate graphs of changes in P^* parameter as well as rock permeability coefficients within the mine roof at a 1.2 m distance from its surface concerning the two considered cases.

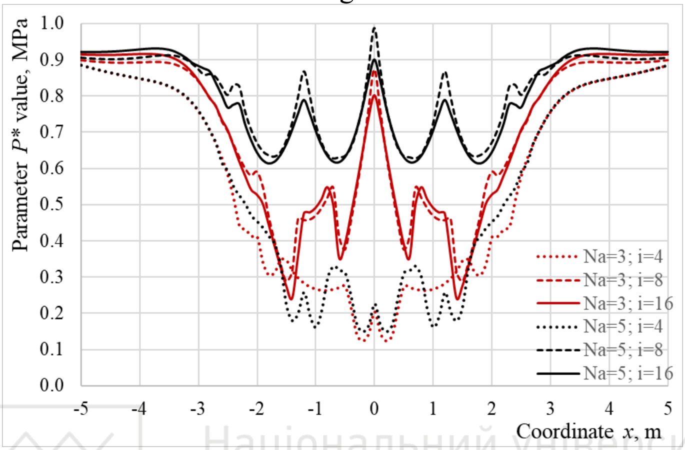

Fig. 8. Changes in P^* parameter values within the mine roof where 3 and 5 injection rock bolts are installed

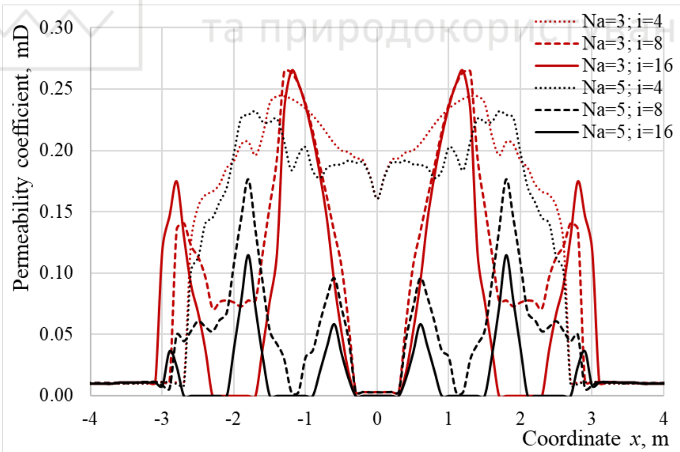

Fig. 9. Changes in the values of permeability coefficients within the mine roof where 3 and 5 injection rock bolts are installed

In the graphs, $x = 0$ coordinate corresponds to the central share of the mine working (i.e. location of the central rock bolt). Coordinates of the mine working walls are ±2,6 m. P^* parameter characterizes a probable rock failure mode: the closer P^* value to a unit is, the more stable near-contour rocks are. Graphs in Fig. 8 show that at the start of a delivery process, if $i = 4$, $P^* \approx 0,15$ for $N_a = 3$ and $N_a = 5$. Such low P^* values stipulates beginning of roof rock transition to unstable state. P^* values increase after the delivery is over and polymer is solidified ($i = 8$-16). If $N_a = 3$ then average P^*_{av} is 0,51; and minimum value is P^*_{min}- 0,24 within the mine working roof $x \in [-2,6; 2,6]$. If $N_a = 5$ then $P^*_{av} = 0,7$, and $P^*_{min} = 0,61$. The increased density of injection rock bolts results in 2,5 times increase of P^* parameter supporting the idea of roof stability improvement.

It follows from Fig. 9 that at the initial delivery stage (when $i = 4$), the values of filtration permeability k achieve 0,23 mD for both supporting schemes at a 1,2 m distance from the mine roof. After the polymer delivery and its solidifying ($i = 8$-16) when $N_a = 3$, k_{max} value increases up to 0,27 mD between the rock-bolt supports (for the assumed initial and boundary conditions). Deep in the rock mass at a 1,2 m distance from the mine roof, the average permeability value is 0.08 mD. If $N_a = 5$ then $k_{av} = 0,02$ mD, and $k_{\max} = 0,1$ mD. Increase in the density of injection rock bolts results in 4 time decrease of the average value of permeability coefficients within the mine roof.

Fig. 10 shows the areas where fracture space of the mine roof are packed with the polymer at different time steps for the considered supporting schemes.

Starting from the 6th time step, the delivery stops. The polymer continues its solidifying; its pressure drops gradually. A filtration process of a liquid polymer is restricted by the rock mass area with rather developed fracture network.

In terms of the assumed initial and boundary conditions, a diameter of one reinforced area is 1.5 m. Nevertheless, in the first case when $N_a = 3$, the areas are not interconnected (Fig. 10*c*, left side); hence, they cannot protect the mine working against failure, gas emission, and water inflow.

If sufficient number of injection rock bolts (five ones in the context of the case) are installed within the mine roof then reinforced arch with low permeability appears (Figs. 10b and 10c, right side). Such an arch is required for the mine working stability, and it becomes the barrier restricting water inflow and gas emission from the undermined rocks into the mine working.

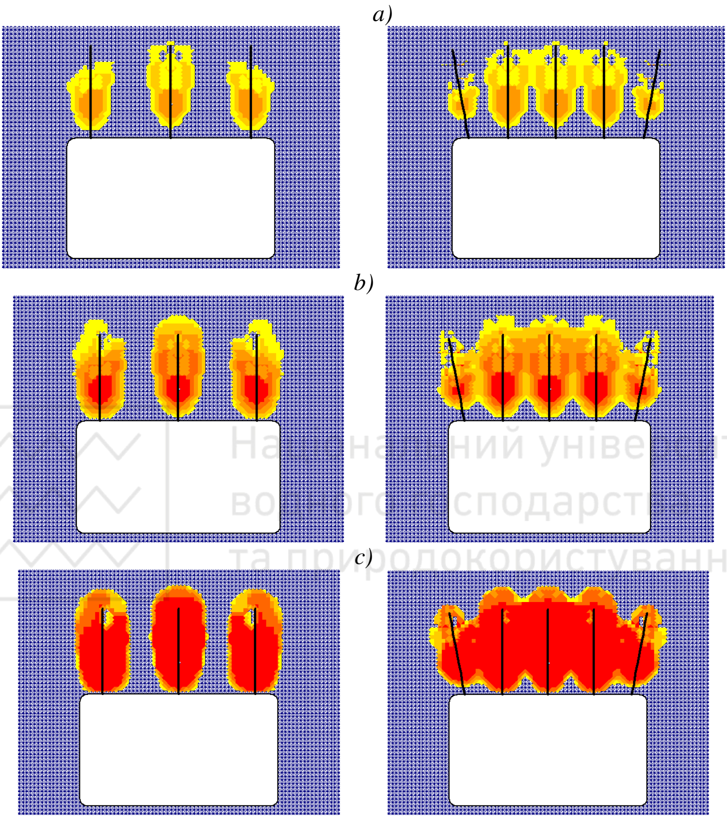

Fig. 10. Roof rock fracture packing with the polymer while installing 3 and 5 injection rock bolts: *a* - $i = 4$; *b* - $i = 6$; *c* - $i = 10$

4.3 Formation of a reinforced rock-bolts arch in the mine roof depending on the initial permeability of host rocks

Let us investigate how the initial permeability of host rocks affects the shape and dimensions of the polymer-reinforced region.

The abovementioned computations have been performed if $N_a = 3$ and initial natural rock permeability is $k_0 = 0{,}01$ mD. It is quite obvious fact that other k_0 values will vary the diameter of the reinforced area around the injection rock bolt (Fig. 11).

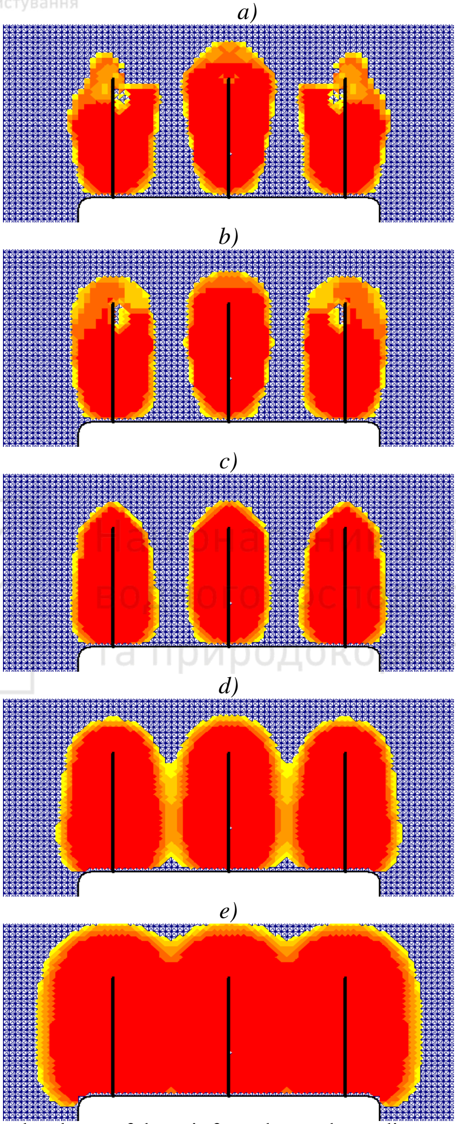

Fig. 11. Changes in the shape of the reinforced area depending on the values of initial permeability: *a* - k_0 = 0,001 mD; *b* - k_0 = 0,01 mD; *c* - k_0 = 0,1 mD; *d* - k_0 = 0,4 mD; e - k_0 = 1,0 mD

In the context of three first cases (Figs. 11*a-c*), the polymer-reinforced areas around the rock bolts are not interconnected; their diameters are almost similar (about 1,5 m). In terms of low initial permeability values (Figs. 11*a* and 11*b*), the upper share of rock-bolt supports is not shaped completely. Proper packing of a fracture space is possible only within the area, influenced by a mine working zone, restricted by the filtration region. If $k_0 > 0{,}1$ mD then the initial permeability starts influencing the reinforced areas diameter: if $k_0 = 0{,}4$ mD they contact (Fig. 11*d*); and if $k_0 = 1{,}0$ mD they form monolith arch (Fig. 11*e*).

Generally, quite typical increase in the dimensions of the reinforcing zone is observed along the increase in the initial rock permeability. Fig. 12 represents dependence of changes in the reinforced area upon the value of initial permeability of host rock for the mentioned conditions of the mine working driving.

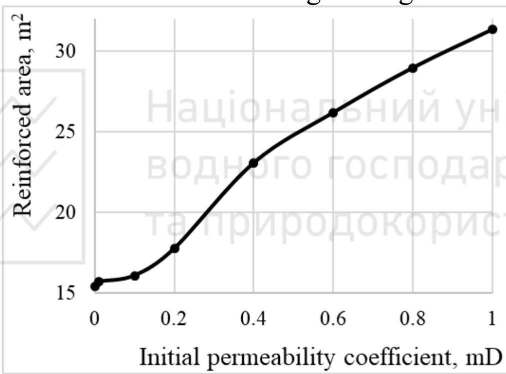

Fig. 12. Dependence of changes in the reinforced area upon the value of initial permeability of host rock

Hence, development of schemes for the mine working support with the help of injection rock bolts should involve following factors determining formation of a permeable zone for a polymer filtration: time from the moment of the mine face was removed; initial rock permeability; and density of injection rock bolts. Consequently, to optimize supporting schemes of the mine working by means of injection rock bolts under specific mining and geological conditions, it is quite expedient to perform early computations using the proposed numerical model.

5 The use of injection rock bolts in combination with steel rock bolts in difficult mining and geological conditions of coal mines in Ukraine

Let us consider a mine working with a cross-section of TSYS-17.7, which is located in disturbed rock near a tectonic fault. We will assume that filtration permeability coefficient $k_0 = 0.01$ mD in the zone of fault influence, and in the immediate vicinity of the dislocation plane $k_0 = 0.1$ mD.

To investigate how the order of installation of steel and injection rock bolts affects the quality of the mine working support, we will consider two cases:

1) at the mine face, at the 3rd time step i, 7 steel rock bolts 2.4 m long are installed; injection of polymer (8 injection rock bolts) is carried out with a lag of 5 m from the mine face, at $i = 10$ (27 h);

2) at the mine face, at $i = 3$, the polymer is injected in 8 injection rock bolts; and 7 steel rock bolts are installed with a lag of 5 m from the mine face, at the 10th time step.

5.1 Changes in the stress state and permeability of host rocks in the process of supporting the mine working

Fig. 13 demonstrates the results of calculating Q^* parameter values, zones of inelastic deformations (red color) and permeability coefficients before installing rock bolts.

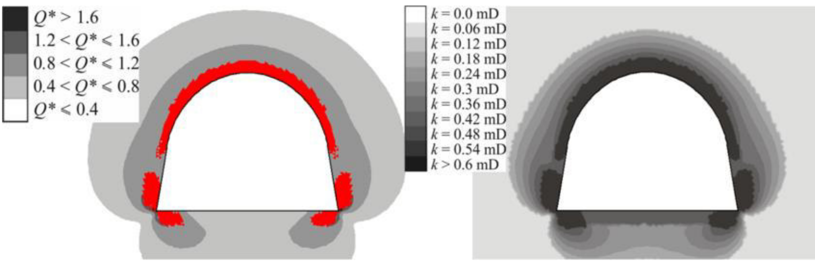

Fig. 13. Distributions of Q^* parameter values and inelastic deformation zones (left side); permeability coefficients (right side) at the time step $i = 2$, $k_0 = 0{,}01$ mD

Extraction of coal and rocks initiates the process of redistribution of the stress field in the host rocks. Since the rocks near the tectonic fault are weakened and disturbed, an area of increased difference of the stress tensor components (parameter Q^*) is already formed around the mine working at the second time step. The vault of the mine working is surrounded by a zone up to 1 m deep, where $0.8 < Q^* < 1{,}2$ (Fig. 13, left side). An inelastic deformation zone, shown in red, appears on the mine working contour, in which the process of fracturing leads to stratification and disintegration of near-contour rocks.

It can be seen (Fig. 13, right side) that the values of the permeability coefficients are not equal to zero even outside the zone of influence of the mine working (light gray color), since the host rocks are disturbed near the tectonic fault. The permeability values vary from 0,01 mD to 0,5 mD at a distance of 1.5 m to the mine working contour.

At the next time step (i=3), rock bolts are installed: in the first case, these are steel rock bolts, in the second case, these are injection rock bolts, through which the polymer is delivered into the fractured space of the host rocks. Let us compare the changes in stress fields and permeability around the mine working over time in these two cases.

Fig. 14 shows the distributions of Q^* parameter values and inelastic deformation zones; Fig. 15 shows distributions of permeability coefficients k for our two cases at different time steps. It can be seen that in both cases, the areas of increased Q^* parameter values around the mine working in the time interval from the 3rd to the 9th time step expand very slowly, almost imperceptibly, since the installation of the rock bolts hinders the process of further unloading of the host rocks from rock pressure.

Small areas are formed around the rock bolts, in which the rocks are in a state of uniform compression ($Q^* < 0{,}4$), similar to the state of undisturbed rocks. However, when steel rock bolts are installed, the area where the values of the Q^* parameter are very high ($Q^* > 1{,}2$) practically disappears (Fig. 14*a*, left side), since, firstly, there are one more steel rock bolts than injection ones. In addition, steel rock bolts come into operation almost instantly, already 30 s after they are installed, immediately after the quick-hardening fixer located in their bottom part has set.

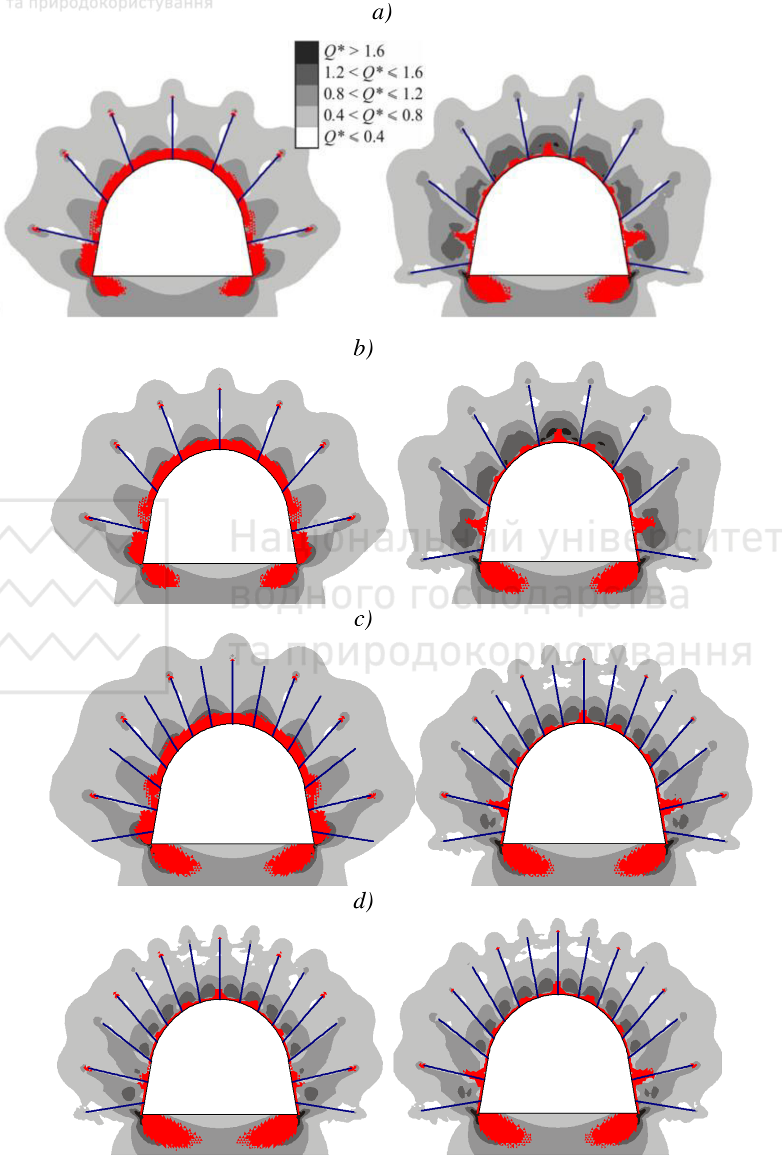

Fig. 14. Distribution of Q^* parameter values and inelastic deformation zones (red color) for the first calculation (left side) and the second calculation (right side) at the time steps: *a* - $i = 4$; *b* - $i = 6$; *c* - $i = 10$; *d* - $i = 20$

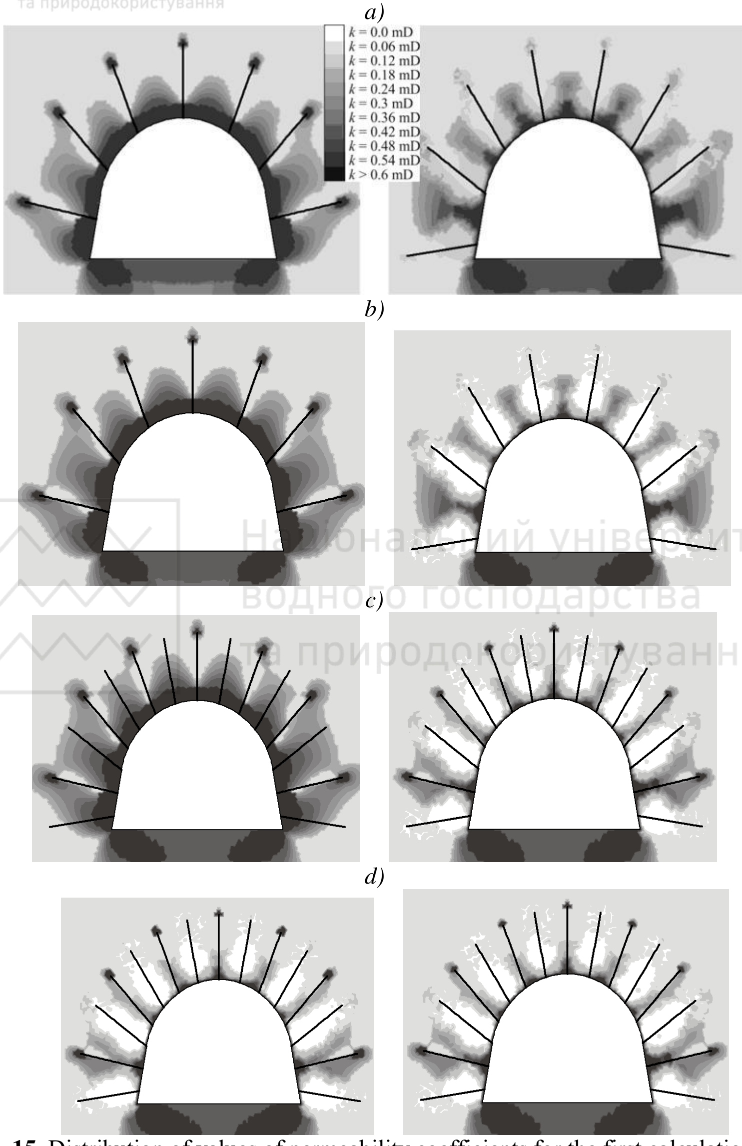

Fig. 15. Distribution of values of permeability coefficients for the first calculation (left side) and the second calculation (right side) at the time steps: *a* - $i = 4$; *b* - $i = 6$; *c* - $i = 10$; *d* - $i = 20$

Conversely, the metal pipe of the injection rock bolt, through which the polymer is delivered, comes into operation only after the delivery is completed and the polymer has solidified.

In the first calculation, when the steel bolts are installed first, the inelastic deformation zones do not decrease after steel rock bolts are installed during the time interval from the 3rd to the 9th time step. Steel bolts do not turn the disturbed rock into a monolith, they fix the state of the host rocks at the time of their installation and do not allow further unloading of the rock mass.

In the second calculation, after the completion of the polymer solidification process (Fig. 14*b*, right side), an region of reinforced rocks, the elasticity modulus and tensile strength of which have increased, is formed around the injection rock bolts. From this point in time, each injection rock bolt is surrounded by a zone of completely impermeable rocks with a diameter of 1,2-1,5 m, which is clearly seen in Fig. 15*b*, on the right side. In the near-contour area, where previously there was a zone of inelastic deformations, due to the binding of stratificated rocks by the polymer, they again acquired the properties of a monolith. However, with a low initial permeability k_0 = 0,01 mD and with a given number of injection rock bolts, there are rocks with high permeability (in this case reaching 0.3 mD) between the impermeable regions. Polymer-reinforced monolithic rock-bolt supports are not sufficiently interconnected, they are separated by areas of disturbed rocks, where $Q^* > 0{,}4$ и $k > 0{,}3$ mD.

At the 10th time step, which approximately corresponds to a five-meter lag behind the mine face, the rock bolts are installed again: in the first case, these are injection rock bolts; in the second, these are steel ones. After that, the disadvantages of suppjrting described above are neutralized. In the first case, the zone of inelastic deformations in the near-contour area disappears, and the stratified rocks become monolithic and strong again. Their permeability is significantly reduced. In the second case, the difference of the stress tensor components in the bolted area decreases. By the 20th time step, both the stress state of the host rocks and their permeability in the two considered cases become almost the same. In the mine roof, the area of uniform compression, where $Q^* < 0{,}4$, increases. Thus, steel and injection rock bolts complement each other very well, increasing the stability of the mine working and reducing the filtration permeability of the host rocks.

Let us construct graphs of the average values of the geomechanical parameters Q^* and P^*, as well as the rock permeability in the bolted area in the process of supporting the mine working for the two considered cases and in the absence of support for comparison, Figs. 16 and 17.

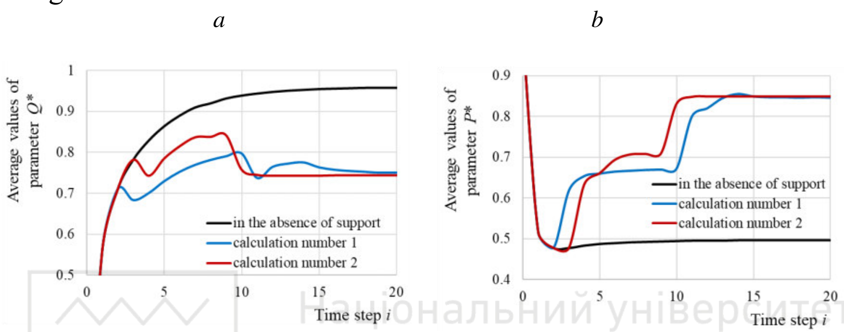

Fig. 16. Average values of the geomechanical parameters in the bolted area around the mine working: *a* -arameter Q^*; *b* - parameter P^*

Over time, the difference of the stress tensor components increases around the unsupported mine working, which leads to fracturing of varying degrees of intensity in the host rocks, Fig. 16*a*, black curve. If the values of this geomechanical parameter decrease, the mine working becomes more stable. The use of steel rock bolts for supporting in the initial time makes it possible to reduce the average value of the Q^* parameter in the bolted area by 12-15% compared to the unsupported mine working (Fig. 16*a*, the time from the 3rd to the 9th time step). If injection rock bolts are installed first, this parameter is reduced by 8-10%. As a result of the combined action of the steel and injection rock bolts, the average value of the Q^* parameter decreases by 22% (Fig. 16a, $i > 15$).

When the free surface is exposed during the excavation of rock and coal, as a result of unloading from rock pressure, the minimum component of the principal stress tensor (parameter P^*) decreases, and if the strength criterion is met, the process of rock destruction will begin. An increase in the value of the parameter P^* in a certain area of the rock mass will bring the state of this area closer to equal-component compression, and the probability of its destruction will decrease. In the period from the 3rd to the 9th time step, when the mine working is supported with only one type of supporting, steel rock bolts increase the average value of the P^* parameter in the bolted area by 30-35%, injection rock bolts increase this parameter by 31-43%, Fig. 16b. Steel rock bolts come into operation faster, and injection bolts, although they gain bearing capacity more slowly, strengthen the rock a little better. In general, by the 20th time step, the average value of the P^* parameter in both cases is increased by 70%, the possibility of near-edge rock destruction is excluded.

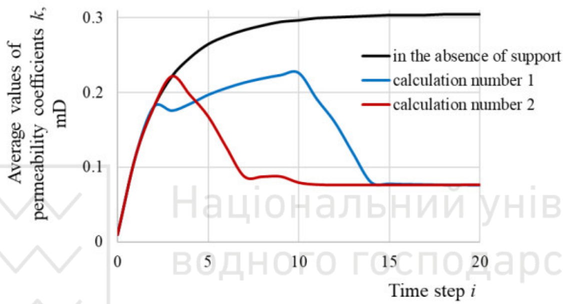

Fig. 17. Average values of rock permeability in the bolted area around the mine working

Fig. 5 shows that the reduction in filtration permeability is mainly due to injection rock bolts. This is because the foamed polymer under high pressure penetrates even into small cracks in the rock and, after it hardens, the possibility of fluid filtration in the consolidated region is excluded. In the first calculation, the average permeability in the bolted area is reduced by 75% compared to the unsupported mine working by the 14th time step. In the second calculation it is reduced by the same amount by the sixth step. If the polymer is injected into disturbed rocks closer to the mine face, then an impermeable shell arch around the mine working will form faster.

If we compare the results of the two calculations, we can see that injection rock bolts exclude the possibility of destruction of host rocks and more effectively reduce the permeability of disturbed rocks in the zone of influence of the tectonic fault. And steel rock bolts better restrain the expansion of the zone of increased difference of the stress tensor components. Therefore, in the case of heavily watered rocks or a high probability of methane breakthroughs into the mine working, it is better to install injection rock bolts and deliver the polymer into the disturbed rock as close as possible to the mine face. Then a water- and gas-proof shell arch around the mine working will be created in the immediate vicinity of the mine face, which will make it possible to quickly prevent emergency water inflows and gas emissions. If there is no such threat and the priority is to maintain the long-term stability of the mine working, then first of all it is necessary to install steel rock bolts with polymer fixing in the borehole. In the rocks fastened with steel bolts, the lateral thrust growths, their residual bearing capacity increases, and the rock displacement into the mine working is significantly reduced. The rock-bolts structure performs its function during the entire period of mine working maintenance.

5.2 Formation of a polymer-reinforced region around the mine working in various zones of tectonic fault

Fig. 18 shows the results of calculation of host rock regions, the fracture space of which is filled with polymer.

The polymer is delivered into the disturbed rock at the 3rd time step in the first calculation and at the 10th time step in the second one. The diameter of one hardened region is 1-1,5 m.

The chemical reaction when mixing the components of the polymer composition proceeds with an increase in its volume. Increasing in volume, the polymer creates additional pressure inside the fractured-pore space of the rock.

The foam composition penetrates under pressure even into small cracks in the rock mass, however, this process is limited by the size of the filtration area around the mine working.

The polymer-reinforced region is not fully formed around each injection rock bolt (Fig. 18*d*).

The bottoms of 6 out of the 8 installed injection rock bolts extend beyond the filtration area. In general, it can be seen that both the first and second supporting schemes by the 20th time step give almost the same result.

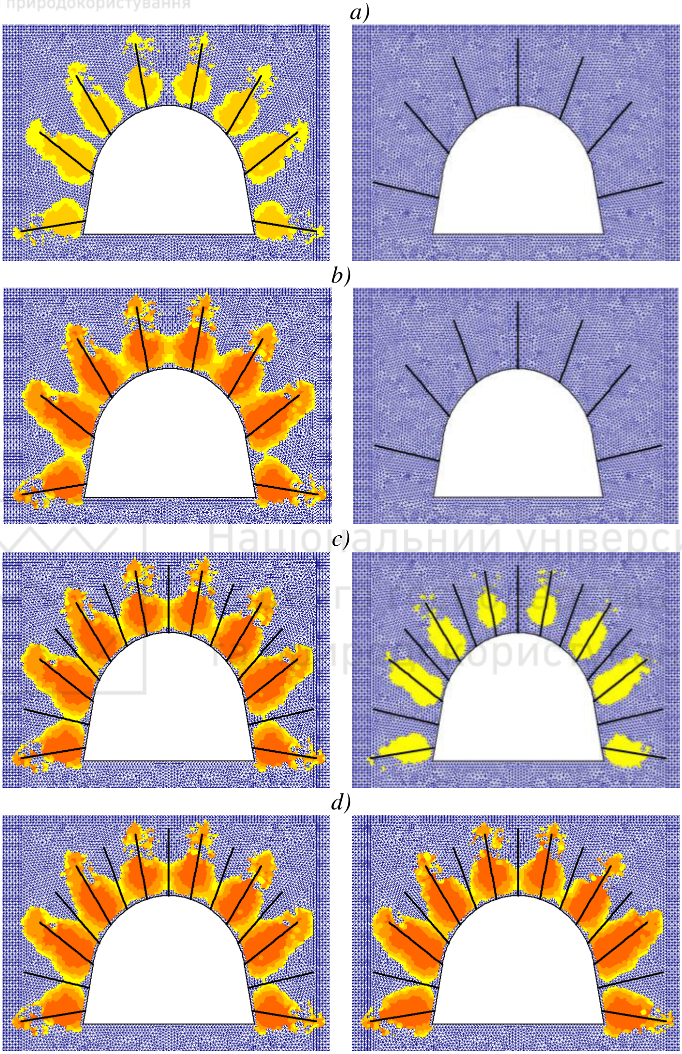

Fig. 18. Host rock regions, the fracture space of which is filled with polymer for the first calculation (left side) and the second calculation (right side) at the time points: *a* - $i = 4$; *b* - $i = 6$; *c* - $i = 10$; *d* - $i = 20$

Let us consider how the shape and area of the polymer-reinforced region will change at a higher initial permeability $k_0 = 0{,}1$ mD in the immediate vicinity of the dislocation plane, Fig. 19.

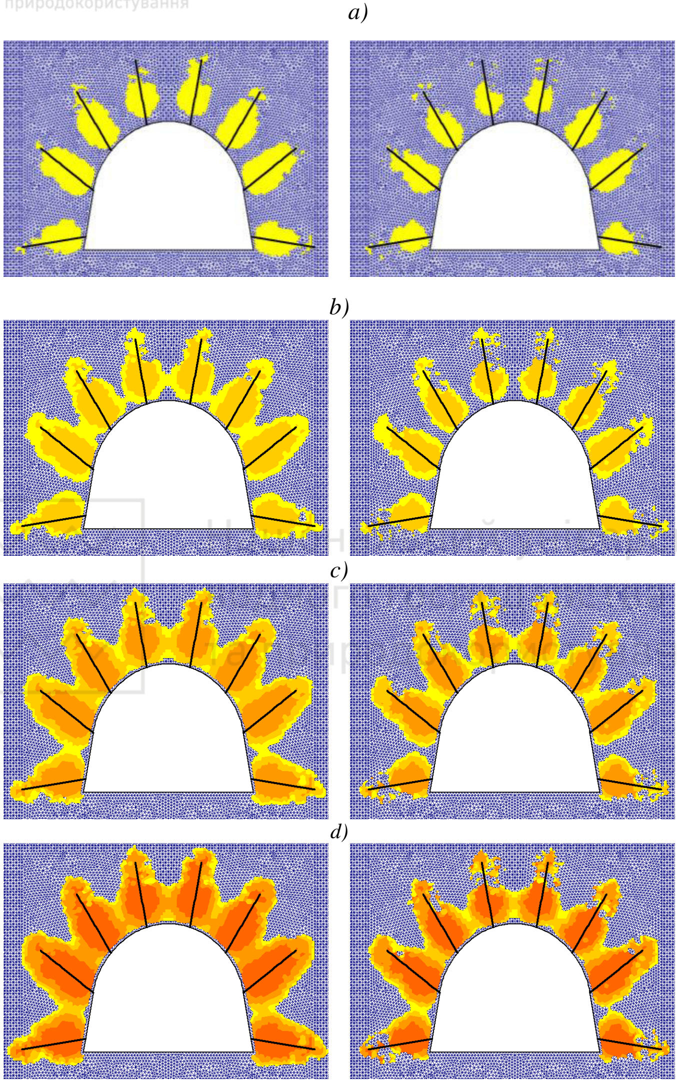

Fig. 19. Formation of polymer-reinforced regions when k_0 = 0.1 mD (left side) and k_0 = 0.01 mD (right side) at the time points: a -t = 5 min after the start of injection; *b*- - t = 10 min; *c* - t = 15 min; *d* - t = 20 min

At k_0 = 0,1 mD, the diameter of reinforced rocks increases, they are in closer contact with each other (Fig. 19, right side), forming a monolithic arch. Such an arch ensures the stability of the mine working and serves as a barrier that restrains water inflow and gas emission from the undermined rocks into the mine working.

In general, there is a regular increase in the size of the reinforced region with an increase in the initial rock permeability. The dependence of the change in the area of the hardened region on the initial permeability of the host rocks for the considered mining and geological conditions is shown in Fig. 20.

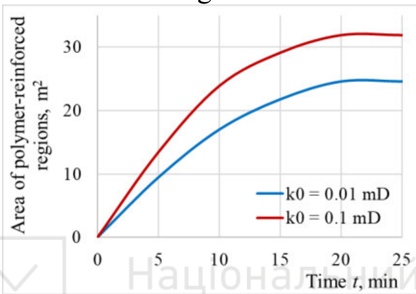

Fig. 20. Areas of the polymer-reinforced regions (in the plane of injection rock bolts installation) in various zones of the tectonic fault, at different values of the initial permeability k_0

When the mine working approaches the dislocation plane and the tectonic permeability increases from 0,01 to 0,1 mD, the diameter of the reinforced rocks around each injection rock bolt increases, they are in closer contact with each other, and the area of the polymer-reinforced region increases by 30%.

5.3 The use of steel and injection rock bolts in coal mines

Supporting technology with steel and injection rock bolts is successfully used in some coal mines of Ukraine when crossing large tectonic faults. For example, the Bogdanovsky fault (one of the largest faults in the Pavlogradsk-Petropavlovsk region) was crossed by a haulage crosscut at the Heroiv Kosmosu mine. The rock displacement amplitude in the work area is 195 m. The width of the disturbed zone is 36,6 m. Fig. 21 shows the supporting scheme.

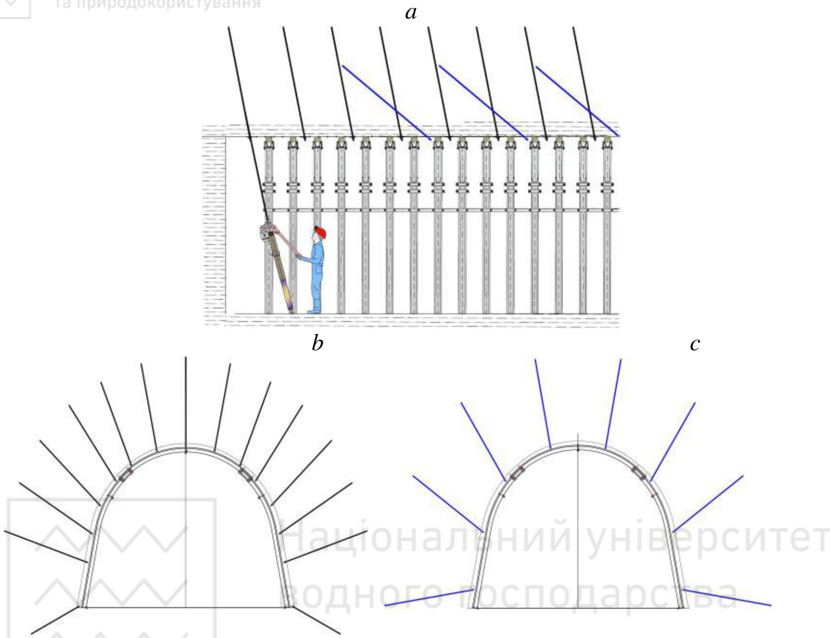

Fig. 21. The supporting scheme for the haulage crosscut: *a* - longitudinal section; *b* - cross section in row with steel rock bolts; *c* - cross section in row with injection rock bolts

The production plan provides for the operation of the haulage crosscut for 25 years. The haulage crosscut was supported with the frame support TSYS-17.7. Rock bolts were installed in the mine face. In order to strengthen the near-contour rocks, polymeric chemical compositions were injected using injection rock bolts with a lag of 5 m from the mine face.

The natural gas content in the coal seam is 8,7-25,2 m^3/t; at the crossing of the fault, the water inflow from 12 to 525 m^3/h was expected [17]. However, thanks to the measures taken when crossing this fault, the mine working remains stable, there are no breakthroughs of gas and water.

6 Conclusions

To study the mechanism of operation of injection rock bolts and the conditions for the formation of the rock-bolts arch around the mine working, a mathematical model of coupled processes of rock deformation and liquid polymer filtration in the disturbed area around the mine working was developed. The problem formulation takes into account the initial permeability of host rocks as well as the permeability due to the mine working driving; time of polymer delivery and hardening; and foaming effect of the polymeric composition in the process of mixing of its components. The changes in physicomechanical and filtration characteristics of rocks during the polymer solidification also were taken into account in the problem formulation as well as the fact that a metal delivery pipe starts operating as a reinforcing element after solidification of the polymeric composition is over.

It was demonstrated that the supporting scheme is important to form a rock-bolts arch. With sufficient density of injection rock bolts, the formed rock-bolts arch may serve as a barrier controlling both water inflow and gas emission from the undermined rocks into the mine working. This rock-bolts arch also ensures its stability. Dependence of changes in the reinforced area upon the value of initial permeability of the host rocks was derived. If the values of initial permeability are low then size of the rock-bolt supports and their shape are determined using only a value of the unloaded zone around the mine working.

Thus, the condition for the formation of a rock-bolts arch around the working with the help of injection rock bolts is the qualitative interaction between reinforced zones around each bolt, which is ensured by the following factors:

- the presence of a filtration area covering the entire zone of injection rock bolts installation with sufficiently high permeability;
- the value of the initial, tectonic rock permeability;
- the amount of time passed from the moment of mine face advance, because of its influence on technological rock permeability;
- the mine working support installed before injection rock bolts, because it also affects technological rock permeability;
- density of injection rock bolts sufficient for high-quality interaction of reinforced zones.

It was shown that steel and injection rock bolts complement each other very well, increasing the stability of the mine working and reducing the filtration permeability of the host rocks. Injection rock bolts exclude the possibility of destruction of host rocks and more effectively reduce the permeability of disturbed rocks in the zone of influence of the tectonic fault. And steel rock bolts better restrain the expansion of the zone of increased difference of the stress tensor components. Therefore, in the case of heavily watered rocks or a high probability of methane breakthroughs into the mine working, it is better to install injection rock bolts and deliver the polymer into the disturbed rock as close as possible to the mine face. Then a water- and gas-proof shell arch around the mine working will be created in the immediate vicinity of the mine face, which will make it possible to quickly prevent emergency water inflows and gas emissions. If there is no such threat and the priority is to maintain the long-term stability of the mine working, then first of all it is necessary to install steel rock bolts with polymer fixing in the borehole.

Supporting technology with steel and injection rock bolts is successfully used in the coal mines of Ukraine when crossing large tectonic faults.

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DEVELOPMENT STRATEGY FOR UNDERGROUND MINING OF RICH IRON ORES CONSIDERING LAND ALIENATION BY KRYVBAS UNDERGROUND MINES

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Abstract

According to preliminary estimates, by 2050, about 70% of mining enterprises in Kryvyi Rih iron ore basin will have exhausted their balance reserves of naturally rich iron ore or reached the maximum economically feasible depth of mining at current production volumes and with the current level of mechanization. Mining enterprises can prolong their performance by mining naturally lean iron ores (magnetite quartzites) which amount to over 5.0 B t. Mining magnetite quartzites by systems with bulk caving of ore and overlying rocks requires abandoning a significant amount of iron ore reserves (over 60%) in protective pollars, or expanding mining and land allotments. Land has to be alloted towards residential and industrial sites of Kryvyi Rih. Land allotment expansion results in increased costs for compensating losses to enterprise owners and for land reclamation. Thus, it is advisable to mine magnetite quartzites applying systems that leave the daylight surface undisturbed, improve the quality of the extracted mineral, increase extraction indicators and reduce disturbed land areas. The research findings can be used in underground mining of naturally lean iron ores at all mines of Kryvyi Rih iron ore basin when working out reserves to a depth of 500 m.

Keywords: underground iron ore mining, sheart zone, land plot alienation, investments, time factor, discounting, discounted capital investments.

Introduction

The mining industry is of strategic importance for economic development and ensuring Ukraine's competitiveness in the global market. The lands provided for subsoil use are the spatial and operational basis for geological exploration of subsoil and location of mining enterprises. Proper organization of land use makes an important area of ensuring performance of a mining enterprise.

The issue of land use for underground mining has been studied by various scholars [1-6], but they mostly consider problems of legal regulation and protection of land provided for subsoil use within the legal regime of industrial land, while specifics of land allocation and use for underground mining remains unaddressed.

The use of land by mining enterprises is characterized by certain specific features due to the fact that the right to use land plots is inextricably linked to the right to subsoil use. These features include, in particular, acquisition of land rights.

The size and configuration of land allotment are determined by the structure of the mining enterprise and parameters of mining allotment in compliance with the state regulations and design documentation approved in accordance with the established procedure. They should be comprehensively justified and minimum required.

Currently, almost all Ukraine's land is assigned to certain owners or users of various categories. The land necessary for subsoil use is not a single land plot falling into the category of industrial land only, but it is located within areas of other categories as well [7-10].

In this regard, in order to carry out almost any work on prospecting, exploration and mining of mineral resources, it is necessary: first, to alienate (buy out, expropriate) a relevant land plot (territory) from its owner or user; secondly, to transfer it to a relevant subsoil user.

Thus, at present, the institution of land alienation from owners and users of land of various categories in favor of mining enterprises for prospecting, exploration and development of mineral deposits is one of the most topical and important.

Alienation of lands of various categories by mining enterprises from owners and users results in new land uses that form the enterprises' land allotment.

Therefore, the enterprise has to allot the newly formed land use for subsoil use needs in order to formalize the right to use it on a lease basis. To do this, the enterprise is first of all to plan the process of land alienation from their owners and users. Further safe and efficient performance of the enterprise depends on its effective implementation.

Analysis of researches and publications

The JSC *Kryvyi Rih Iron Ore Plant* (*Kryvbaszalizrudcom*) is one of Ukraine's largest underground iron ore mining enterprises. The *Ternivska* mine is one of four underground mines that are part of the JSC *Kryvbaszalizrudkom* and was commissioned in 1963 [11].

The mine works out a deposit of naturally rich ores and magnetite quartzites located in the north of Kryvyi Rih iron ore basin and is administratively part of Ternivkyi district of Kryvyi Rih, Dnipropetrovska oblast.

The *Ternivska* underground mining allotment covers 426,5 hectares, and its boundaries (Fig. 1) run along those of Ordzhonikidze mining allotment (the PrJSC *Central GZK*) in the south and on the territory of T ernivkyi district of Kryvyi Rih in the north, east and west.

The mining allotment contains mine shafts and complexes of industrial facilities, a caving and shear zones, dumps, and *Gorky* residential area in the northern part.

The ore deposit is opened in the center of the mine field by one ore-hoisting shaft of the *Ternivska* mine currently sunk to a depth of 1425 m, and two ventilation shafts on the flanks: the *Flanhova* mine in the south and the *Pivnichna-Ventyliatsiyna* mine in the north. The *Flanhova* shaft is sunk to 1350 m, and the *Pivnichna-Ventyliatsiyna* one – to 1200 m.

At the *Ternivska* mine, the ore deposit is mined applying level (sub-level) induced caving systems, mainly a level-room system with a level height of 75 m and many options of sub-level caving.

Currently, the *Ternivska* mine extracts iron ore from the 1275-1350 m level. Mining is performed by double levels with a total height of 150 m, of which the level 1275 m is intermediate and the level 1350 m is the main one [12-15].

The mine's industrial site has a full range of technological buildings and facilities for receiving and processing raw ore, producing and shipping commercial products.

Fig. 1. Surface plan of the Ternivska mine of the JSC Kryvbaszalizrudkom:
1 – mining allotment; *2* - land allotment

As of 2022, the mine's annual production capacity is 1,161 Mt.

The mine has also started introducing imported high-performance mining equipment.

The land allotment of the *Ternivska* mine consists of three separate land plots, see. Fig. 1, located in the industrial and production zone of Ternivskyi district of the city within the mine's mining allotment. The land plots are not a single area, they are separated from each other by common use roads that are access ways to other users' plots located within the mining allotment of the *Ternivska* mine. The total area of the land allotment is 244,5516 hectares.

Extraction of large volumes of rocks from the subsoil and their movement to another territory change the stress-strain state of rocks, [16-20]. And this, in turn, affects the processes of rock mass displacement which can reach the surface and cause strains and destruction of industrial and civilian facilities located in this zone, Fig. 2.

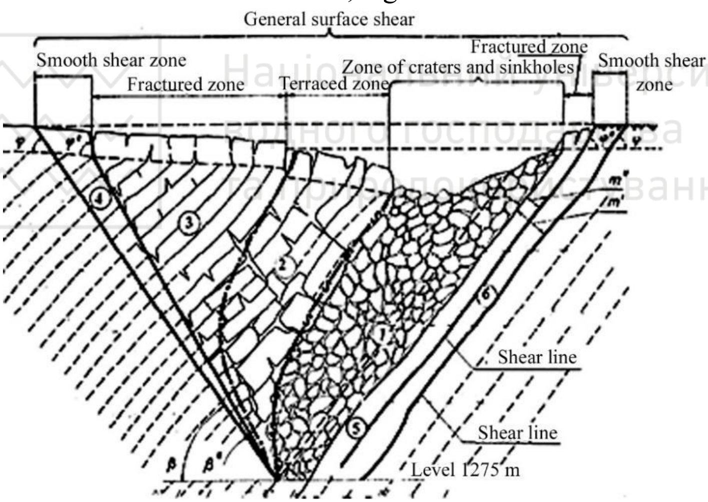

Fig. 2. Areas and zones of various strains of the massif and the earth surface in the across the strike section of the sheet-like deposit: *1* – the caving area; *2* - the shear area; *3* – the fractured area; *4* – the area of smooth deflection; *5* - the area of the layer shear; *6* - the area of smooth shear of layers

Depending on the specific combination of mining, geological and technological factors, the process of rock displacement can be localized at depth or, having reached the surface, manifest itself in various forms such as craters, sinkholes and other disturbances of the surface.

Thus, underground mining operations and extraction of millions of tonnes of rock mass from the subsoil using systems with induced caving of ore and country rocks result in significant man-made disturbances of the geological structure of the subsoil in the form of cavities within the mine's mining allotment. Gravity makes the rocks surrounding such cavities move, thus causing development of rock displacement which leads to formation of a general shear zone on the earth surface consisting of areas of various strains.

Ore deposit mining is accompanied with shears and the threat of sudden sinkholes that cannot be predicted timely. Therefore, all industrial and public surface and underground facilities, artificial and natural reservoirs that fall within the zones of influence of underground workings are subject to changes, damages, destructions and complications that disrupt their normal operation mode.

According to technological design standards of mining enterprises [21], facilities that fall within the design zone of dangerous strains should be relocated beyond this zone or protected from deleterious effects of mining operations.

When designing underground mining operations, it is necessary to determine feasibility of developing new areas of deposits at depths below the hoisting capabilities of mine shafts [21,22].

According to the "Rules for protection of structures and natural objects from the temporary impact of underground mining operations in Kryvyi Rih iron ore basin" [23], the feasibility study identifies the design zones of earth surface shear caused by iron ore deposit mining to the level 1500 m in two options:

- option I – working out all reserves to the 1500 m level;
- option II - mining the reserves with part of ore abandoned in pillars to protect the surface of the residential area.

The design boundaries of the earth surface shear zones of the two reserve mining options are shown in Fig. 3.

According to *option I*, when mining all reserves up to the level 1500, the design shear zone includes a significant part of *Gorky* residential area and the ponds, see Fig. 3. This option provides for relocation of residential buildings and utilities that fall within the shear zone caused by rich ore mining to the level 1500 m. Thus, according to option I, the following are subject to relocation: 302 private households, 2 shops, a school, a kindergarten, a gas distribution point, an Orthodox church, housing and utility buildings and the ponds.

Option II involves mining the deposit reserves while abandoning part of ore in protective pillars to prevent disturbances of the residential area surface, see Fig. 3. For this purpose, pillars within surveying axes 70-78 and 109-117 are mined from the 1350 m level with an extension to the 1500 m level by planes inclined at 85° to the level. The width of the pillars along the strike is 94 m on the 1350 m level and 120 m on the 1500 m level.

Fig. 3. Formation of the shear zone and the new land use within its boundaries for subsoil use needs at the *Ternivska* mine, the JSC *Kryvbaszalizrudkom*: *1* – boundaries of the mining allotment of the *Ternivska* mine; *2* – boundaries of the land allotment of the *Ternivska* mine; *3* – design boundaries of the earth surface displacement zone when mining naturally rich iron ores without leaving pillars, level 1350-1500 m, the *Ternivska* mine (option I of the feasibility study); *4* – design boundaries of the earth formation according to option II of the feasibility study accepted for further deposit mining, the *Ternivska* mine

The mentioned pillars on the 1350-1500 m level along with the existing ones on the 1200-1350 m level ensure localization of the shear zone on the earth surface within the shear zone resulted from mining the deposit to the 1500 m level. The earth surface beyond the shear zone resuled from mining the deposit to the 1500 m level remains undisturbed. The residential area and the ponds are preserved. That is, according to option II, only 109 private households and a shop that fall within the design shear zone are subject to relocation.surface displacement zone when mining naturally rich iron ores with pillars left, level 1350-1500 m, the *Ternivska* mine (option II of the feasibility study); *5* – protective pillars (option II of the feasibility study); *6* – the area of a new land use

Thus, the area of land to be alienated under option II of the deposit mining is much smaller compared to that under option I, see Fig. 3.

The areas of the earth surface shear zones caused by iron ore mining to the 1500 m level of the *Ternivska* mine of the JSC *Krybaszalizrudkom* under the mentioned two options are shown in Table 1.

Land plots are alienated as the shear zone develops.

Table 1

Areas of shear zones caused by mining the naturally rich iron ore deposit to the 1500 m level

Zone	Area, hectares	
	Option I	Option II
Shear zone	269	153
including:	-	-
zone of probable crater formation	120	92
fractured zone and shear zone (boundaries coincide)	149	61

Based on the feasibility study [24], for further ore reserves mining on the 1350-1500 m level of the *Ternivska* mine, option II of mining rich iron ores is accepted. According to it, part of ore is abandoned as protective pillars. The option ensures localization of the shear zone on the earth surface within the shear zone resulted from mining the deposit to the 1500 m level, and prevention of part of *Gorky* residential area, which will then be beyond the zone, from earth surface disturbances.

According to the second option of the feasibility study, the design boundary of the shear zone caused by mining on 1350-1500 m level dermines the boundary of the mine's new land use area which is to be allocated for subsoil use needs of the JSC *Kryvbaszalizrukom*, Fig. 3.

To ensure the timely and efficient implementation of the process of alienation of private land plots that will fall into the earth surface shear zone during further deposit mining at the level 1350-1500 m, the enterprise should first address the issue of its effective planning.

Purpose

The *research aims* to ensure the further safe and efficient performance of a mining enterprise applying the underground mining method by improving the planning of the process of alienating land plots of the shear zone during further iron ore reserves mining at the *Ternivska* mine of the JSC *Kryvbaszalizrudkom* through determining the optimal scenario for investing in the alienation process, considering its dynamics conditioned by spesifics of the deposit mining technology.

For this, the following *tasks* should be solved:

1. To study the dynamics of the land alienation process in space and time, considering spesifics of the technology for mining the deposit at the *Ternivska* underground mine
2. To plan the enterprise's investments in land alienation by developing investment scenarios for the alienation process, considering its dynamics in space and time conditioned by spesifics of the mining technology.
3. To assess economic efficiency of the developed investment scenarios for the alienation process, considering the time factor, and in accordance with the established optimality criterion, to determine the cost-effective (optimal) investment scenario for the alienation process.

Metods

A wide range of general scientific methods, including traditional ones of empirical and theoretical knowledge, are used to conduct research into land management uses. The empirical research methods include observation, description, experiment, comparison, measurement, questionnaire-based survey, testing, etc. In addition to these specific methods, at the empirical level of scientific knowledge methods that are general (general logical) for both the empirical and theoretical levels are used such as abstraction, induction and deduction, generalization, analysis and synthesis, analogy, modeling, etc [25].

The methods of analysis and synthesis are associated with division of the land management object under study into its constituent elements and their combination into a single whole, respectively. A more complex mathematical analysis, as a rule, is applied to determine the influence of certain factors (values, arguments) on the dependent variable (function, result).

1. Methods of monetary valuation of land plots

For all categories of land in settlements (except for agricultural land and water fund land plots used for fish farming), the normative monetary value of one square meter of land is determined by the formula

$$C_n = \frac{B \times H_n}{H_k} \times K_f \times K_m, \tag{1}$$

where C_n is the normative monetary value of 1 m^2 of land, UAH; B is the cost of developing and arranging the territory per 1 m^2, UAH; H_n is the profit margin (6%); H_k is the capitalization rate (3%); K_f is the coefficient describing the functional use of a land plot (for residential and public buildings, industry, transportation, etc.); K_m is the coefficient describing the land plot location.

The coefficient describing the land plot location (K_m) is determined by three groups of regional, zonal and local rent-forming factors and calculated by the formula

$$K_m = K_{m1} \times K_{m2} \times K_{m3}, \tag{2}$$

where K_m is the coefficient describing the land plot location; K_{m1} is the coefficient describing regional factors of the land plot location, in particular: population and administrative status of the settlement, its place in the settling system; location within settlements in the suburban areas of large cities; accommodation within settlements with the status of resorts; K_{m2} is the coefficient describing zonal factors of land plot location within settlements, in particular: distance to the settlement center, concentrated workplaces, and recreation places; location in the core of large cities and other settlements of particular historical importance, in the coastal zone of settlements; K_{m3} is the coefficient describing local factors of the land plot location in terms of territorial planning, engineering and geological, historical and cultural, natural landscape, sanitary and hygienic conditions and the level of territory arrangement.

Normative monetary valuation of land in settlements is carried out in three stages [26,27].

At the first stage, the average (basic) cost per square meter of land in a settlement, which depends on location of the settlement in the national, regional and local production and settling systems and the level of development and arrangement of the territory, is determined by the formula

$$C_{nm} = \frac{B \times H_n}{H_k} \times K_{m1}. \quad (3)$$

At the second stage, within a settlement, the base value of one square meter of land is differentiated by economic and planning zones, which are established on the basis of an economic assessment of the settlement territory, considering heterogeneity of functional and planning qualities of the territories that influence the amount of rental income; accessibility to the settlement center, labor activity centers, public service and recreation centers; the level of engineering support and landscaping; development of the public service sector; environmental qualities and attractiveness of the territories. The cost of one square meter of land in settlements by economic planning zones is calculated by the following formula

$$C_{nz} = C_{nm} \times K_{m2}. \quad (4)$$

At the third stage, the monetary valuation of individual land plots is carried out. The value of one square meter of a land plot of a certain functional purpose is determined considering the territorial-planning, engineering and geological, historical and cultural, natural landscape, sanitary and hygienic, engineering and infrastructure features of its location within the economic planning zone according to the formula

$$C_n = C_{nz} \times K_f \times K_{m3}. \quad (5)$$

The normative monetary value of a land plot is subject to indexation. The general procedure for indexation of the normative monetary value of land is established by Art. 289 of the Tax Code of Ukraine [28], according to which the State Service of Ukraine for Geodesy, Cartography and Cadastre annually calculates the indexation coefficient of the normative monetary valuation of land based on the consumer price index for the previous year, by which the normative monetary valuation of agricultural land, land of settlements and other non-agricultural land is indexed as of January 1 of the current year.

Thus, considering indexation of the normative monetary value, (5) takes the following form

$$C_n = C_{nz} \times K_f \times K_{m3} \times K_i \,, \tag{6}$$

where K_i is the coefficient of indexation of the normative monetary value of land, which is applied cumulatively depending on the date of the normative monetary value of land.

2. Economic and mathematical method of research

Capital investment planning at an enterprise involves calculating the required amount of production investments for the calculation period and determining sources of capital financing.

Development of an enterprise's investment strategy is a necessary condition for its efficient investment activity and includes the following:

- formulating investment activity directions and a system of long-term goals;
- deciding on the most effective ways to achieve the goals.

The official methodology for assessing the economic efficiency of production investments (capital investments) involves determining their overall (absolute) or comparative (feasibility assessment) economic efficiency.

An indicator of the comparative efficiency of capital investments is the *discounted costs minimum* (B_{pr})

$$B_{pr} \;=\; C_i + E_n \times K_i \rightarrow min \,, \tag{7}$$

where B_{pr} is the discounted capital expenditures (investments), UAH; C_i is the cost of annual output under the i-th investment option, UAH; E_n is the normative coefficient of capital investments efficiency; K_i is investments under the i-th option, UAH.

Thus, when developing possible scenarios for investing in the process of land alienation, its dynamism in time and space should be considered. In order to assess economic efficiency of capital investments and determine the optimal investment scenario, it is advisable to use the comparative efficiency of capital investments under each scenario, considering the time factor, accepting the discounted capital expenditures minimum as the optimality criterion.

The difference in the time of capital investments is considered by discounting them to the same period of time using the *discount factor* *e*, which is determined by the expressions:

a - to discount earlier expenditures to any later year

$$e_p = \left(1+E_n\right)^{t_k}, \tag{8}$$

b - to discount later expenditures to any earlier year

$$e_n = \frac{1}{\left(1+E_n\right)^{t_k}}, \tag{9}$$

$$t_k = t_d - t_i, \tag{10}$$

where E_n is the discount rate, or the normative coefficient of capital investment efficiency (considers the degree of entrepreneurial risk, in a typical methodology for determining economic efficiency of capital investments for a mining enterprise, it equals 0.08 [28, 29]); t_k is the indicator of the power of the discount factor, which is equal to the time interval between the year of discounting and the year of investment, years; t_d is the serial number of the year of capital expenditures discounting; t_i is any *i*-th year of capital expenditures, which is counted from the beginning of the alienation process and varies from 1 to *t* years.

Practical application of discounting to determine the discounted current value of cash flows requires appropriate financial and mathematical formalization of the discounting model - determining the absolute value of the discount.

In a typical methodology for determining economic efficiency of capital investments for ferrous metallurgy enterprises, the size of the discount rate varies within 0,08÷0,15 [28, 29].

Thus, efficiency of capital investments is significantly influenced by inflation and risk, considering the fact that the discount rate takes these factors into account.

Capital investments can be made in several stages with different implementation periods. Any year from the beginning of the investment project can be taken as the moment of assessing efficiency of capital investments within the life of the project. Thus, considering (8) and (9), the total discounted capital expenditures are calculated by the following formulas

$$K_{pr.p} = K_1\left(1+E_n\right)^{t_d-1} + \ldots + K_i = \sum_{1}^{t} K_i\left(1+E_n\right)^{t_d-t_i}, \tag{11}$$

$$K_{pr.n} = \frac{K_1}{\left(1+E_n\right)} + \frac{K_2}{\left(1+E_n\right)^2} + \ldots + \frac{K_i}{\left(1+E_n\right)^{t_1-t_i}} = \sum_{1}^{t} \frac{K_i}{\left(1+E_n\right)^{t_d-t_i}}, \tag{12}$$

where $K_{pr.p}$, $K_{pr.n}$ are the discounted capital investments (expenditures) from the earlier to any later year and the later to any earlier year, respectively, M UAH; t is total duration of the investment project, $t=t_I+t_{II}+\ldots+t_N$, years; t_I, $t_{II},\ldots$, t_N are duration of the first, second, ..., N-th period of the investment project, years; K_i is initial capital expenditures of any i-th calendar year of the investment project, UAH;

Thus, using the discounting method, future capital expenditures (investments) are discounted to the current value, resulting in comparable absolute values of the cost of future capital expenditures.

Results

According to the feasibility study [24], for further working out at the 1350-1500 m level of the *Ternivska* mine, the second option of mining rich iron ores is accepted which provides for abandoning part of ore in protective pillars and determines the design boundary of the earth surface shear zone. The design boundary of the shear zone determines the boundary of the area for formation of a new land use of the mine, which is to be alienated for the needs of subsoil use by the JSC *Kryvbaszalizrudkom*.

Thus, due to necessary forced abandonment of disturbed land (earth surface shear zone), a new land use is being formed on part of the territory of *Gorky* residential area between the design boundary of earth surface shear zone caused by mining to the 1500 m level (according to the second option of the feasibility study) and the boundary of the mine's current land allotment - the fourth component of the *Ternivska* mine's land allotment.

Within the newly formed land use there are lands of two forms of ownership - private (land of the residential buiding area – citizens' personal land plots) and communal land (public lands that are free from development, not provided for ownership or permanent use).

The design boundary of the shear zone caused by deposit mining to the 1500 m level (according to the second option of the feasibility study), which determines the boundary of the territory for a new land use of the *Ternivska* mine, runs accross the area of some land plots on Bakinska, Tychyna, Shchelhunov and Heroiv Brestu streets, dividing them into parts. That is, it is not the total area of these land plots that is subject to alienation, but their parts that fall within the shear zone.

The boundaries of the design land use shown in Fig. 4 coincide with actual boundaries of the land plots in the north, east and west, and run along the boundary of land plot No.1 of the current land allotment of the mine [30].

Fig. 4. Designed new land use of the *Ternivska* mine: *1* – boundaries of the mining allotment of the *Ternivska* mine; *2* – boundaries of the land allotment of the *Ternivska* mine; *3* – design boundaries of the earth surface displacement zone when mining naturally rich iron ores without leaving pillars, level 1350-1500 m, the *Ternivska* mine (option I of the feasibility study); *4* – design boundaries of the earth surface displacement zone when mining naturally rich iron ores with pillars left, level 1350-1500 m, the *Ternivska* mine (option II of the feasibility study)

The total area of the newly formed land use within the designed boundaries (see Fig. 4) makes 20,1724 hectares.

Thus, our research considers the generalized areas of individual land plots within their design boundaries at certain addresses and the design total area of residential development land under the land plots to be alienated, which is 16,6652 hectares.

Due to mining operations, the process of land alienation is dynamic in space and time. Its dynamics in space is described by *se-*

quence (alienation of a certain number of land plots in the corresponding land use area), and in time - by *duration* of alieniation. These characteristics are the basis for planning the alienation process.

Given the iron ore mining technology of the *Ternivska* mine, the sequence and duration of the process of alienating privately owned land plots should be established.

According to the feasibility study [24,30], alienation of all privately owned land plots within the designated area of land use under residential development is planned for the time of completion of the mine reserves up to the 1350 m level, i.e. before starting operations at the level 1350-1500 m.

The sequence of land alienation consists in determining certain parts of the land use area with the corresponding number of land plots within them to be alienated in the first and second place.

As mentioned above, the mine is currently producing iron ore at the 1275-1350 m level. Therefore, further mining of the deposit to a depth of 1500 m involves creation of two levels - 1425 m and 1500 m, which form two floors - 1350-1425 m and 1425-1500 m, respectively, with each of them creating the corresponding boundaries of the shear zones on the earth surface.

Thus, first, the 1425 m level is worked out and a shear zone is formed from the 1350-1425 m level, then the 1500 m level creates a shear zone of the 1425-1500 m level, Fig. 5.

Fig. 5 displays the boundaries of the shear zones caused by mining 1350 m, 1425 m, and 1500 m levels on the surface plan. They determine development of the earth surface shear process with further increase of the deposit mining depth up to 1500 m and establish the sequence of land alienation by shear zones within which they fall.

The land use area beyond the shear zones is conditionally divided into *alienation zones*. Fig. 6 shows that each of them includes a certain number of land plots subject to alienation.

Alienation zone I is created between the boundary of the current land allotment and the design boundary of the shear zone when mining the 1350-1425 m level. Its boundaries run along the boundary of the current land allotment and boundaries of land plots, and its area makes 4.2089 hectares;

Alienation zone II is created between the design boundaries of the shear zones during mining 1350-1425 m and 1425-1500 m levels. Its boundaries run along those of land plots and its area makes 12,4563 hectares.

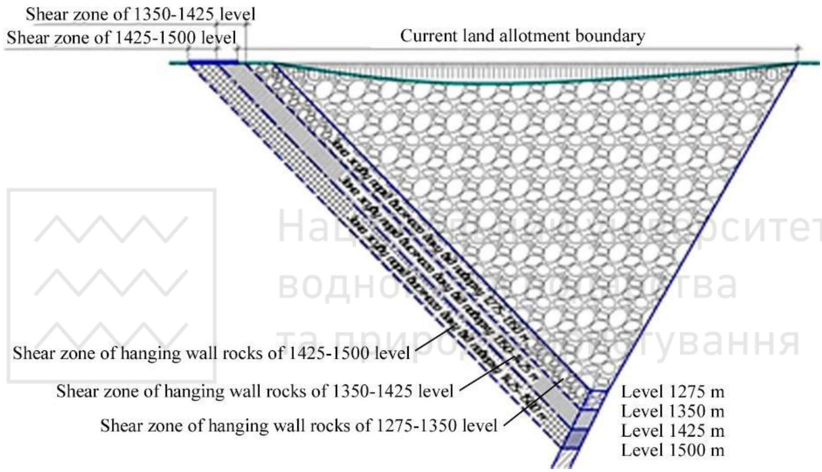

Fig. 5. Rock and earth surface shear zones caused by mining the 1350-1425 m and 1425-1500 m levels on the across the strike section of the *Ternivska* mine deposit of the JSC *Kryvbaszalizrudkom*

Thus, the sequence of land plot alienation is determined by the technological sequence of mining levels and development of the shear zone with further increase in the mining depth and shoud be as follows.

To work out the 1350-1425 m level, it is necessary to alienate the first zone at the time of completion of the 1350 m level and the beginning of creation of the 1425 m level (before completion of the 1275-1350 m level).

To work out the 1425-1500 m level, it is necessary to alienate the second zone at the time of completion of the 1425 m level and the beginning of creation of the 1500 m level (before completion of the

1350-1425 m level), Fig. 7.

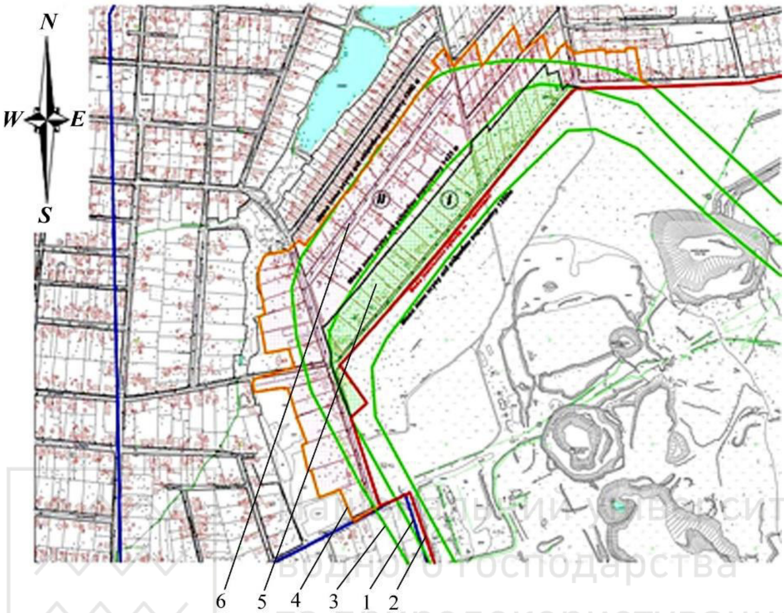

Fig. 6. Division of land use of the *Ternivska* mine into alieniatinon zones corresponding to the shear zones caused by mining the respective levels: *1* - the boundary of the mining allotment of the*Ternivska* mine; *2* - the boundary of the current land allotment of the*Ternivska* mine; *3* - the newly created land use between the design boundary of the share zone (feasibility study option II) the boundary of the current land allotment of the*Ternivska* mine; *4* - boundaries of the shear zone caused by mining levels 1350, 1425, 1500 of the*Ternivska* mine; *5* - alieniation zone I – land plots that fall within the shear zone when mining the level 1350-1425; alieniation zone II – land plots that fall within the shear zone when mining the level 1425-1500

At the same time, it follows from the above that duration of alienation of land plots of each zone within the shear zone caused by mining the corresponding level is limited to the period of mining the previous (higher) level.

Thus, duration of alienation of land plots in zone I (the shear zone caused by mining the level 1350-1425 m) is limited to duration of mining the level of 1275-1350 m, and zone II (the shear zone caused by mining the level 1425-1500 m) - to duration of mining the level 1350-1425 m.

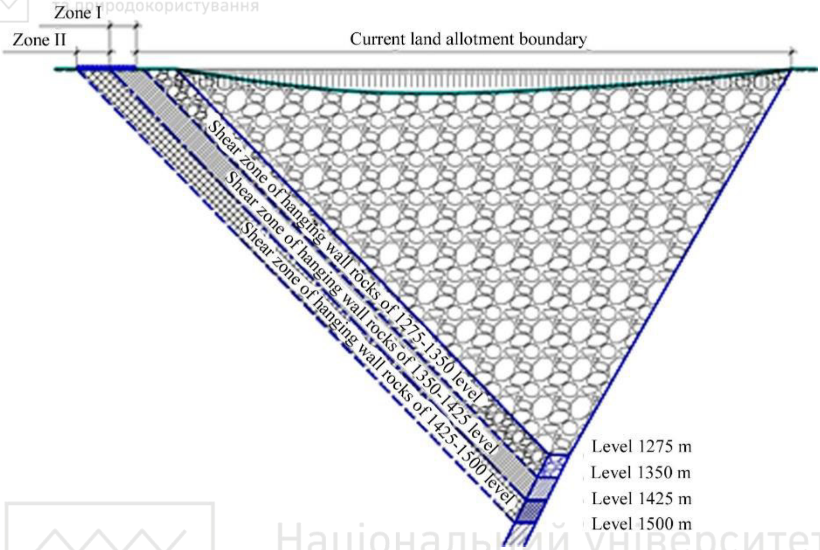

Fig. 7. Land alienation zones on the across the strike section of the *Ternivska* mine deposit of the JSC *Kryvbaszalizrudkom*

Duration of zone alienation can be found by the formula for determining duration of level mining [29]

$$t_v = \frac{Q}{A} + t_r + t_e \quad , \tag{13}$$

where $t_в$ is duration of zone alienation (duration of mining the level), year; Q is the amount of reserves in the level, Mt; A is the annual productivity of the enterprise, Mt; t_r is the period of the level creation, years; $t_з$ is the period of completion of mining the level, years; t_r=t_e=1,5 years, since a new level is created simultaneously with completion of the previous one.

For the purpose of calculations, the year 2017 is taken as the beginning of the mining period for the level 1275-1350 m. The amount of reserves in the levels 1275-1350 m and 1350-1425 m makes 11,923 Mt and 11,359 Mt respectively [30]. According to the JSC *Kryvbaszalizrudkom* data, the annual productivity of the *Ternivska* mine is 1,161 Mt.

Let us study the dependency of alienation duration for land plots of each zone on the change in the volume of commercial production when mining reserves of the levels 1275-1350 m and 1350-1425 m. Based on calculations by (13), a diagram can be built to demonstrate the dependency of land alienation duration on the mine's annual productivity, Fig. 8.

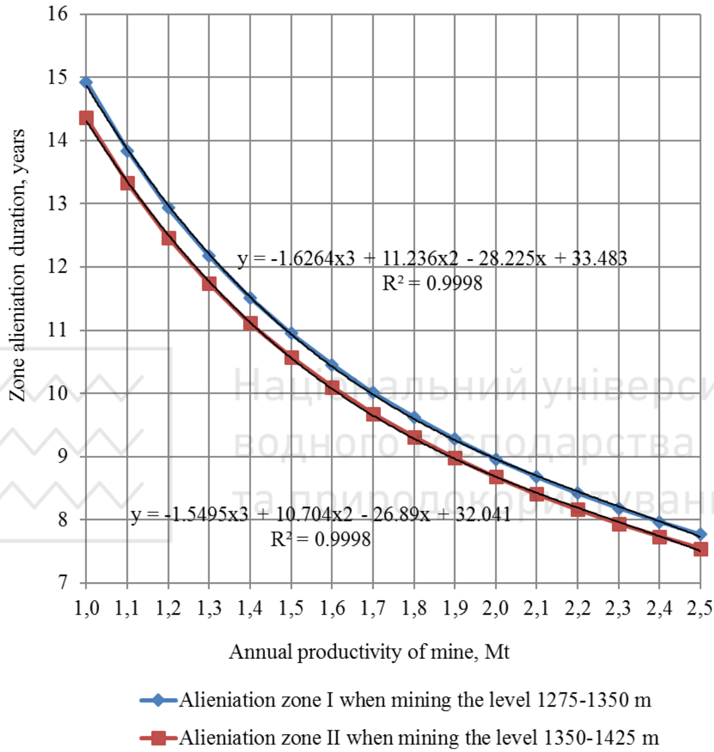

Fig. 8. Dependency of land alienation duration for two zones on the annual mine productivity and the amount of reserves in levels

Fig. 8 shows that with an increase in annual productivity of the mine from 1,0 to 2,5 Mt, duration of zones I and II alienation period decreases from 14,9 to 7,8 years and from 14,4 to 7,5 years respectively.

The obtained calculated values of duration of each zone alienation depending on commercial production volumes described by annual productivity are well approximated by polynomial curves of the third power. The latter are determined by the following equations

$$t_v = -1{,}6264A^3 + 11{,}236A^2 - 28{,}225A + 33{,}483\,, \qquad (14)$$

$$t_v = -1{,}5495A^3 + 10{,}704A^2 - 26{,}895A + 32{,}041 \qquad (15)$$

Equations (14, 15) enable determining duration of the process of land plot alienation for zones I and II when mining the levels 1275-1350 m and 1350-1425 m with the corresponding amount of reserves in them with different annual productivity.

Thus, we have established that the dependency of land plot alienation duration for each zone on the annual productivity of the mine can be approximated with a high probability by a polynomial curve of the third power. The reliability of the R^2 approximation for the diagnosed curves is determined as well, see. Fig. 8.

Thus, alienation duration for zone I (the shear zone caused by mining the level 1350-1425 m) is equal to duration of working out the level 1275-1350 m; alienation duration for zone II (the shear zone caused by mining the level 1425-1500 m) equals duration of working out the level 1350-1425 m.

Land plots included in zone I must be alieniated during 13 years within the period of 2017-2029, and those of zone II – during 13 years within the period of 2030-2042. The total duration of privately owned land plot alienation for the two zones of the land use under study makes 26 years and covers the period of 2017-2042.

Despite the fact that the land plots to be alienated are not similar in terms of their main characteristic – availability and condition of real estate objects (built-up or vacant), they are similar in terms of administrative and territorial location and the engineering and transport infrastructure.

The redemption normative value of land plots is calculated by areas of alieniation zones they belong to; the total initial investment required by the JSC *Kryvbaszalizrudkom* to carry out the alienation process is determined as well. The redemption value of a land plot (normative value) is found by the following formula

$$B_d = C_n \times S\,, \qquad (16)$$

where B_d is the redemption value of the land plot (normative value), UAH; C_n is the normative monetary value of 1 m^2 of the land plot, UAH; S is the area of the land plot, m^2.

To apply (16), the normative value of 1 m^2 of the land plot (C_n) of residential land should be found first.

Thus, the enterprise should invest 19,448 M UAH to alienate land plots in zone I and 57,554 M UAH in zone II. The total amount of initial investment required by the enterprise to alienate the total area of land plots is 77,002 M UAH.

Given the dynamism of the land alienation process in space and time, when planning this item of capital investment, an enterprise should consider several investment scenarios and perform economic assessment of their efficiency.

At an enterprise applying the underground iron ore mining method (underground mine), the minimum specific discounted costs for extraction of 1 t of ore are used as a criterion for its optimal productive capacity [29,30]

$$B_{pr} = C + E_n \times K \rightarrow min, \quad (17)$$

where B_{pr} is the specific discounted value cost per 1 t of ore mined, M UAH/t; C is annual operating specific costs, M UAH/t, E_n is the normative capital investment efficiency coefficient; K is specific capital expenditures, M UAH/t.

To decide on the best investment scenario, comparative economic efficiency indicators are used, which consider only those cost parts that change in comparable options.

In our case, we believe that the operating and other capital expenditures of the mine, except for the cost of land alienation, are fixed.

Therefore, under our conditions, (17) is adaped and the criterion of the optimal investment scenario for land alienation is determined as the specific discounted capital investment minimum by the formula

$$B_{pr.i} = \frac{K_{pr.i}}{Q} \rightarrow min, \quad (18)$$

where $B_{pr.i}$ is the specific discounted value of capital investments (costs) for land alienation, UAH/t; $K_{pr.i}$ is the discounted value of capital investments (expenditures) for alienation of land plots, M UAH; Q is the amount of reserves in the level to which capital investments for alienation of land plots of the corresponding zone are attributed, M t.

The initial amount of investment is assumed to be the same for each scenario of investing in land alienation and estimated at 77,002 M UAH. The spatial division of the land use under study into alienation zones determines their compliance with stages of investment in the alienation process, and periods of capital investment correspond to those of zone alienation.

Given the above indicators and conditions of their application, let us consider *two scenarios* of investing in the process of alienation of privately owned land plots, which differ in terms of their implementation:

1. *Simultaneous investment* in the process of alienation of land plots of zones I and II during 13 years (2024-2036). When mining the 1275-1350 m level, we invest in alienation of land plots in zones I and II during 13 years.

2. *Staged investment* in the process of alienation of land plots in zones I and II during 26 years (2024-2049). At the first stage of the scenario, when mining the level 1275-1350 m, funds are invested during 13 years (2024-2036) for alienation of land plots of zone I, at the second stage - during the next 13 years (2037-2049) in mining the level 1350-1425 m - zone II.

For each investment scenario, even and uneven (with increased and decreased funding) options for distribution of capital investments by years are provided for.

We consider it expedient to discount capital investments in alienation of land plots at the time of zone I alienation completion (late 2036 - early 2037), which corresponds to the period of completion of mining the level 1275-1350 m and the beginning of mining of the level 1350-1425 m, since it determines the space and time distribution of the alienation process.

The item of capital expenditures for alienation of land plots of zone I refers to capital expenditures for mining the level 1350-1425 m, and the item of capital expenditures for alienation of land plots of zone II refers to capital expenditures for mining the level 1425-1500 m.

For the first investment scenario, we need to invest in alienation of zone I and zone II simultaneously, i.e. earlier, when the level 1275-1350 m is mined, so we need to make earlier investments and discount them to a later year. Thus, the capital investment for the simultaneous alienation of land plots of zones I and II is discounted to the end of this investment scenario implementation - late 2036 (the 13th year).

For the second scenario, the investment is made in two stages:

- at the first stage, we discount earlier investments to a later year of investment - capital investments for alienation of land plots of zone I are discounted to the end of the implementation period of this investment stage - late 2036 (the 13th year of the investment stage);

- at the second stage, we discount later investments to the earlier year of investment - capital investments for alienation of land plots of zone II are discounted to the beginning of the implementation period of this stage of investment - at early 2037 (the 1st year of the investment stage).

Thus, for each of the studied options of by-year distribution of capital investments for the two scenarios of investing in land alienation, we discount different time periods of capital investments to the same period of 2036-2037 through the normative indicator of their efficiency (discount rate) of 0.08 and obtain comparable absolute values of future capital investments, the analysis of which enables an adequate management decision on investing in the alienation process.

Based on the determined values, diagrams of dynamics of the discounted capital investment amounts can be built according to different options of their distribution by years for two scenarios of investment in the process of land alienation (Fig. 9, 10).

Comparison of the total values of the initial and discounted capital investments in alienation of privately owned land plots under two investment scenarios with different options for distribution of capital investments by years, demonstrates that, considering the time factor, the amount of capital investments changes. This dynamics is plotted in Fig. 11.

Thus, at even distribution of capital investments by years, the total amount of the discounted value of capital investments under the first scenario (simultaneous investment in two alieniation zones during 13 years) increases from 77,002 M UAH to 127,321 M UAH, and under the second one (staged investment in each zone during 26 years) decreases from 77,002 M UAH to 67,150 M UAH.

Uneven distribution of capital investments by years is considered in two options: with increased and decreased funding. The total amount of the discounted value of capital investments under the first scenario increases from 77,002 M UAH to 106,561 M UAH and 148,080 M UAH respectively, under the second one it decreases from 77,002 M UAH to 59.983 M UAH and 74,310 M UAH respectively.

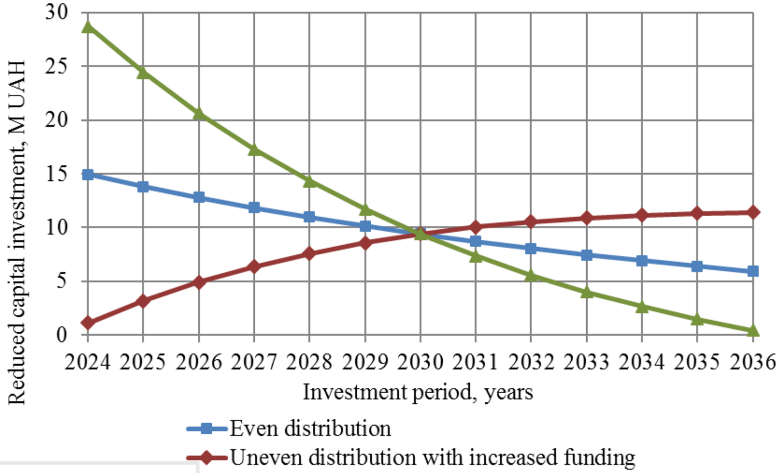

Fig. 9. Dynamics of the discounted capital investments by different options of their distribution by years of the first scenario of investment in land plot alienation

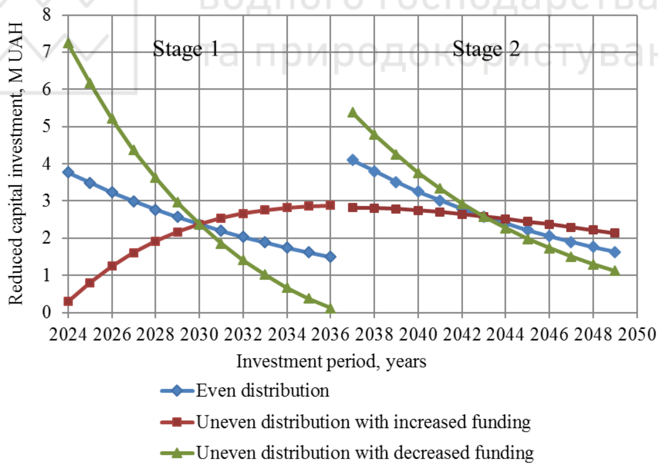

Fig. 10. Dynamics of the discounted capital investments by different options of their distribution by years of the second scenario of investment in land plot alienation

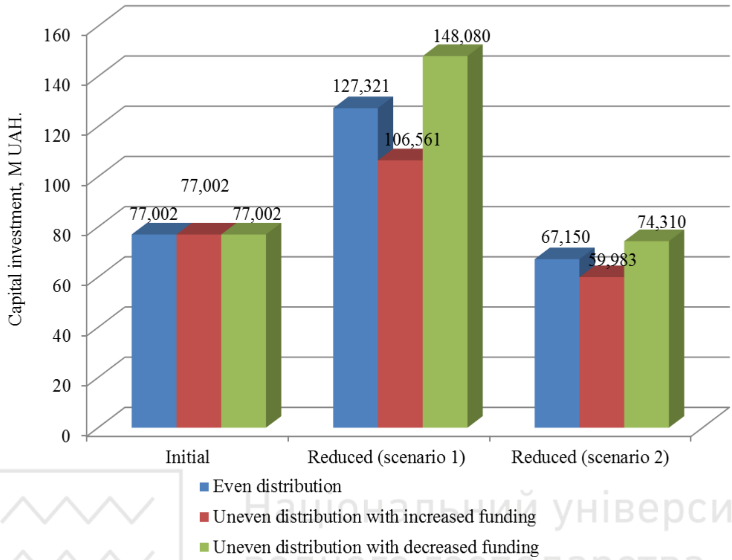

Fig. 11. Comparison of amounts of the initial and discounted capital investments by two investment scenarios for the process of land alienation under different options of their distribution by years

Thus, the amount of the discounted value of investments for alienation of land plots depends on the term of their implementation and the selected value of the normative indicator of their efficiency (discount rate).

Comparison of the calculated total values of the discounted capital investments in alienation of privately owned land plots under two investment scenarios with different options for distribution of capital investments by years, demonstrates that for all options of distribution the amount of the discounted capital investments under the second scenario is less than the first one, see. Fig. 11.

Thus, at even distribution of funds by years, the amount of the discounted value of capital investments under the first investment scenario (simultaneous investment in alieniation of zones during 13 years) equals 127,321 M UAH and under the second one (staged investment in each zone during 26 years) - 67,150 M UAH, i.e. 60,171 M UAH less.

At uneven distribution of capital investments by years considered in two options with increased and decreased funding, the amount of the discounted value of capital investments under the distribution options for the first scenario is 106,561 M UAH and 148,080 M UAH respectively. For the second one it makes 59,983 M UAH and 74,310 M UAH, which is less by 46,578 M UAH and 73,770 M UAH respectively.

Thus, the research enables establishing that it is advisable to plan investments in alienation of privately owned land plots that fall into the zone of earth surface shear during further mining of the *Ternivska* mine's iron ore deposit to a depth of 1500 m according to the second scenario, which is more cost-effective than the first one and consists in staged investment in land alienation: at the first stage of the scenario, when mining the level 1275-1350 m, funds are invested in alienation of zone I land plots during 13 years (2024-2036), and at the second stage - during the next 13 years (2037-2049), when mining the level 1350-1425 m of zone II. Investments within the timeframe of each stage should be distributed unevenly, their volumes increasing by years.

Conclusions

The research conducted enables the folloing main conclusions:

1. It is advisable to develop investment scenarios that differ not only in terms of their implementation, but also in terms of options for distributing capital investments by years (even and uneven with an increase and decrease in funding), which allows for more thorough investment analysis and planning.

2. Consideration of the time factor (discounting capital investment days to one period through a discount coefficient that takes into account inflation and business risks) when performing a comparative economic assessment of efficiency of capital investments in land alienation enables obtaining their comparable absolute values (current value of future investments), which in turn enable making adequate management decisions on investing in alienation in market economy conditions.

3. For the *Ternivska* mine of the JSC *Kryvbaszalizrudkom*, it is established that efficiency of the land alienation process is ensured

by applying its optimal investment scenario, which provides for staged investment in the alienation process: stage 1 - alienation of zone I during 13 years (2024-2036) when mining the 1275-1350 m level, stage 2 - alienation of zone II during 13 years (2037-2049) when mining the 1350-1425 m level, applying uneven distribution of capital investments within the timeframe of each stage with an increase in the amount of funding by years.

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ON THE ISSUE OF ENVIRONMENTAL CONSEQUENCES OF CLOSING COAL MINES

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Abstract

According to the above research, the main factors determining the ecological situation as a result of the production activities of coal mining enterprises are the pollution of the atmosphere by dust and gaseous products, the change of the water balance as a result of the mixing of surface and underground waters, the deformation of the earth's surface with the formation of landslides. The closure of coal mines leads to a change in the ratio of the influence of these factors on the state of the ecosystem. This is due to the reduction of emissions of dust and gaseous products into the atmosphere, an increase in the level of underground water and its impact on

the stability of rocks in the zones of extinguished production, as well as flooding of adjacent territories. The study is based on the analysis, systematization and generalization of the results of the effects of coal mining enterprises on the environment from known literary sources and consists in establishing the conditions for the formation of processes that determine the ecological environment during the operation of a coal enterprise and comparing these processes with the processes after the cessation of production activities.

Introduction

The experience of operating and shutting down coal mining enterprises has shown a fundamental difference between the processes that accompany their activities at these stages in terms of the impact on the environment and the state of the earth's surface.

During the operation of a coal mine in the usual mode, the main attention is paid to creating safe conditions for underground mining, since in all cases they are classified as especially dangerous . These hazards are associated both with direct technological operations and the need to create conditions acceptable for human life in underground conditions. These such an influence, the scheme of the main flows of mine gases (Fig. 1) can conditions are provided, first of all, by ventilation of mine workings and pumping of water to the earth's surface. These forced technological processes over a long period of operation of a coal enterprise cause changes both in the state of the rocks enclosing the coal seams and affect the environmental situation in the vicinity of the operated mine. As an example of serve.

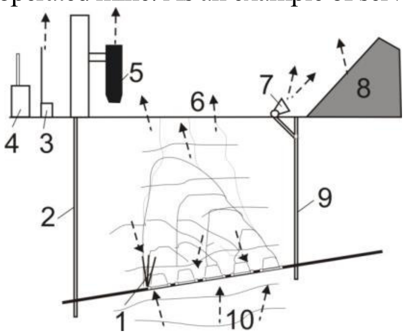

Fig. 1. Scheme of the main flows of mine gases [1]: *1* - capturing by degassing wells; *2* - transport along mine workings with rock mass and water; *3* - vacuum pumping unit; *4* - disposal plant; 5 - separation from coal in bunkers and warehouses; *6* - isolation from soils; *7* - emissions with ventilation flows; *8* – extraction from rock dumps; *9* - transport along mine workings with a ventilation jet; *10* - residual gas in the bowels

A similar scheme characterizes the processes of water movement during its pumping from mine workings and host rocks to the earth's surface, which also causes certain changes in the environment and in host rocks in the zones of influence of mine workings.

Dumps of coal mines and processing plants are objects of increased environmental hazard, as they are not only sources of constant release of harmful substances, but also in some cases the cause of landslides with the movement of the rock mass over long distances [2].

The history of the development of Donbass exceeds 200 years. More than 21 billion tons (up to 12 km^3) of rocks have been extracted from the bowels, including about 15 billion tons (10 km^3) of coal. As a result of such activity, deformations occurred with a violation of geomechanical equilibrium and continuity of 600 km^3 of the rock mass in the zones of influence of mining, and on 50% of the area, subsidence of the day surface averaged 1.5÷2.0 m with a simultaneous increase in rock permeability and increased interaction surface and ground waters [3].

It follows from the state of the issue that the main factors that determine the environmental situation as a result of the production activities of coal mining enterprises are air pollution with dust and gaseous products, changes in the water balance as a result of mixing surface and ground waters, deformation of the earth's surface with the formation of displacement troughs.

The closure of coal mines leads to a change in the ratio of the influence of these factors on the state of the ecosystem. This is due to a reduction in emissions of dust and gaseous products into the atmosphere, an increase in the level of groundwater and their impact on the stability of rocks in the zones of extinguished workings, as well as flooding of adjacent territories. Reliable forecasting of possible environmental consequences of mine closure is impossible without establishing the initial state of the ecosystem, which was formed as a result of production activities.

The methodology and idea research. The idea is to establish the conditions for the formation of processes that determine the ecological environment during the operation of a coal enterprise and compare these processes with processes after the cessation of production activities. The goal is to establish trends in the processes that determine the environmental consequences after the closure of mines. The methodology is based on a comparison of the factors and processes that determine the state of the ecosystem in the conditions of an operating enterprise and after its liquidation.

Results and discussions. The safety rules [4] do not allow the operation of burning dumps. In Ukraine, there are approximately 220 rock dumps, which should be classified as burning, since, despite the fire extinguishing measures taken, there are separate fires and harmful substances are constantly emitted on them [2]. The amount of harmful substances emitted is about 500 thousand tons per year [5]. The restructuring of the Ukrainian coal industry through the liquidation of unprofitable and unpromising mines began in 1996. In the Donetsk region, 223 rock dumps were transferred for liquidation, including 48 burning ones. According to the project schedules, the reshaping, extinguishing, landscaping and other environmental protection activities at the rock dumps were to be completed in full by 2014. In fact, design solutions were implemented only for 63 waste dumps due to the systematic underfunding of mine liquidation projects. Along with this situation, a systematic monitoring of the temperature state of burning heaps was carried out, and on most of the burning dumps from 2006 to 2014, a decrease in temperature by 100-200 °C was established. On seven dumps, the temperature decreased to 80 °C, which made it possible to transfer them to the category of non-burning [6]. If we proceed from the dynamics of temperature decrease, then the attenuation of burning dumps without environmental protection measures can occur after the liquidation of the mine within 10-15 years. According to the results of the surveys, it was found that 90% of the dumps are self-greening , most of them have already been self-greened by 10-80%. This confirms the propensity of the considered system of the biosphere to self-healing [7]. Implementing environmental measures can significantly speed up the process of self-healing. The closure of coal mines contributes to the attenuation of fires in rock dumps and the restoration of the surrounding biosphere.

The elements of the biosphere that do not have the ability to reproduce include landscape and subsoil [7]. The change in the landscape of the earth's surface is caused by the extraction of coal seams of different thicknesses and at different depths. The displacement of the earth's surface during the treatment works causes deformation of various structures and objects located on coal-bearing territories, and has an adverse effect on them. When mining under watered rocks, reservoirs and streams, the deformation of rocks leads to the formation of water-conducting (through) cracks in the rock mass, water breakthroughs into mine workings and their flooding. The subsidence of the earth's surface under the influence of underground mining can cause flooding of the settled areas of the earth's surface with groundwater, atmospheric and flood waters.

The main types of displacements and deformations that are dangerous for undermined structures and natural objects include: subsidence (vertical displacements of the earth's surface), slopes (differences in vertical displacements of neighboring points, referred to the distance between them), curvature (the ratio of the difference in slopes of neighboring sections to distance between them), horizontal displacements (displacements of the earth's surface in the horizontal plane), horizontal deformations (the ratio of the difference between horizontal shifts of neighboring points to the distance between them). The slopes of the earth's surface cause the instability of tall objects and lead to an unacceptable change in the profile of railway tracks, etc. The curvature and horizontal deformations of the earth's surface can cause damage to buildings, structures, industrial complexes, pipelines, mine workings and other objects. For vertical mine shafts and mine workings, compression or tension of rocks along the vertical is dangerous.

The study of the parameters of the displacement of rocks and the earth's surface, as well as the development of methods for protecting undermined buildings, structures, mine workings, natural objects from the harmful effects of underground mining are urgent tasks directly in the extraction of minerals:

1. Determination of the boundaries of the zone of harmful influence of underground mining on structures and other objects. This problem arises when placing the designed surface structures, mine workings, including mine shafts, when establishing the need to take measures to protect structures and planning mining under a built-up area.

2. Determination of the safe depth of development, which is understood as such a depth below which the mine workings cannot cause destructive deformations in the undermined objects, entailing the termination of operation, danger to the life of workers and living in protected buildings and structures.

3. The use of mining engineering and structural protective measures when excavating coal under structures. The basis for these activities are the magnitude of displacements and deformations of the foundations of structures.

4. Leaving safety pillars of coal as a protection measure used when other methods cannot guarantee the normal operation of the protected object or are economically unprofitable.

5. Establishment of conditions for rational extraction of coal under forest plantations, rock dumps and water bodies.

The practical solution of these problems is regulated by a normative document [8]. According to it, the boundaries of the zones of influence of mine workings and the duration of the process of displacement of the earth's surface, the calculated and permissible indicators of deformations of the earth's surface for residential and public buildings, industrial buildings, engineering structures and communications, railways and technological equipment are determined. Special requirements are imposed on the rational excavation of coal under water bodies, forest plantations and rock dumps.

When conducting mining operations, the main influencing factors that contribute to the achievement of the earth's surface by the processes of displacement of undermined rocks are [9] the thickness of the developed reservoir (m) and the depth of work (H). In all cases, without exception, the operation of modern coal mines causes the earth's surface to move. According to the nature of the manifestation, the process of displacement of the earth's surface can manifest itself in the form of dips, funnels, large cracks, ledges, microcracks, and smooth deformations. Subsidence of the earth's surface can cause flooding of settled areas of the earth's surface with groundwater, atmospheric and flood waters, but consideration of such issues at the stage of operation of a coal enterprise, as a rule, was not considered. More relevant during this period of mine operation are measures to prevent water breakthrough into existing mine workings [10, 11]. The watering of workings can be different, but even in slightly watered mines there are cases of water breakthrough from several tens to a thousand cubic meters per hour. The largest number of water breakthroughs is confined to sandstones and limestones. In the case of preliminary drainage, water inflow into individual wells is up to 20-40 m^3/hour for three to six months [10]. Water breakthroughs into mine workings are emergency situations that are not typical for the period of normal seam mining. The main amount of water is pumped out of the mine workings during the stable operation of the mines. It is characterized by the volume of pumped water for each ton of mineral resources - the coefficient of water abundance . This figure for the Donetsk coal basin averages about 2.8 m^3/t [12]. With such abundance of water in the mines of Donbass, more than 30 billion m^3 of water was diverted to the surface during the entire period of their operation.

There are general, district and downhole water inflows . The total water inflow to the mines consists of: groundwater inflow (aquifers drained by mine workings); mine waters coming from flooded workings and neighboring mines; water supplied to the mine for backfilling, irrigation, well drilling, etc.; surface water and precipitation. The mode of water inflow into workings depends on the combination of interacting natural (climatic, geomorphological, hydrogeological) and technological (shape and size of the mining area, depth and intensity of field development, development system) factors [13].

The district water inflow consists of inflows into the development workings and into the goaf of the excavation area. Water enters the development workings from minerals, aquifers lying directly in the roof and soil of the workings, or from drainage wells. Water inflows , reducing the pace of tunneling, contribute to the intensification of the drainage of aquifers within the prepared excavation areas. Water enters the mined-out space mainly from aquifers that fall into the zone of water-conducting cracks, from neighboring worked-out areas, and sometimes from the surface of the earth.

Downhole water inflow is made up of the inflow of groundwater and water from the mined-out area, which enters directly into the bottomhole area of development and treatment workings.

The zone of water-conducting cracks is a disturbed rock mass, through the cracks of which underground and surface waters enter the mine workings. There are zones of natural water-conducting cracks associated with large tectonic disturbances and karst phenomena, and artificial ones - with the displacement of rocks above the goaf and deformation of the rocks, as a result of which cracks form, causing the connection of aquifers and surface waters with the goaf [13].

In the Donetsk basin, on an area of up to 15 thousand km 2 , as the depth of mining operations increased (up to 900-1300 m) and the level of groundwater decreased under the influence of mine drainage, a regional imbalance in the system “mineral skeleton of rocks - groundwater” increased.". The consequence of the new hydrogeological conditions was the development of a local-regional depression level surface of groundwater. The deepening of active water exchange zones from 150÷250 to 450-550 m with a corresponding increase in atmospheric precipitation infiltration and the inflow of technogenically modified surface waters from rivers, reservoirs, ponds and other water bodies into aquifers led to a change in the natural balance. As a result of mine water exchange , hydrochemical conditions were leveled due to mixing of surface and ground waters and an increase in their mineralization due to leaching of salts from rocks and pore solutions. As a result of long-term drainage in the area of mining operations in the free-flow filtration zone (fractured-soil horizon), a regional depression funnel with a depth of 40-50 m was formed. those. 800-1000 m. The volume of dried rocks is 150÷200 km ^{3} [3]. Large radii of influence of depression surfaces indicate a high degree of depletion of water resources in the area of activity of mining enterprises and water intake facilities [7]. In the Donbass, in the upper zone of the geological environment, a quasi-equilibrium system "mine water - mineral skeleton" was formed for some time. This led to a change in the natural configuration and direction of groundwater flows, a technogenic increase in the activity of the relationship with surface waters, and a change in the structure of the sources of formation of their resources [3].

Changes in hydrogeological conditions give rise to the following negative changes in the geological environment, ecosystems: depletion of groundwater reserves; extraction of gravitational water from waterproof rocks; drainage of wells, streams and reservoirs; violation of the water-salt regime of rocks in the aeration zone; deterioration of the quality of ground and surface waters.

If we compare Dniprobass with Donbass, then the negative impact of coal industry enterprises on the environment, associated with changes in the ecological environment, is much stronger in Donbass. The mineralization of underground and surface waters in the Dneprobass does not currently exceed 1 g/l, and in the Donbass it is 2-35 g/l and more. Significantly different in these regions and the chemical composition of water, as well as the degree of influence of coal industry enterprises on rivers and reservoirs. These comparisons are not in favor of Donbass [14].

One of the urgent environmental problems of the coal-mining regions of Ukraine is the negative phenomena and processes that accompany the liquidation of mines and cuts. They are of a multivector nature and in one way or another are connected with the restoration of the natural levels of groundwater drained during the operation period. TO the main ones are flooding and swamping of the earth's surface, changes in the chemical composition of ground and surface waters, activation of the earth's surface movement over workings, deterioration of the physical and mechanical properties of rocks, and extrusion of mine gases [15].

In general, the flooding of mines in the Donbass from 1996 to 2014 led to flooding from 20 to 40% of the territories adjacent to them. The management of groundwater inflows at different stages of the post-operational existence of liquidated mines is a poorly understood process of water migration in a disturbed massif [16] and requires further detailed study.

The liquidation of individual mines also poses a threat of flooding of neighboring enterprises, since there is a risk of water breakthrough through the barrier pillars [17]. This makes it necessary to pump out water in volumes close to the productivity of drainage systems of previously operating mines [18]. In its essence, such a measure is limited to the life of neighboring mines, and after their closure, in any case, it is necessary to develop other measures to mitigate environmental consequences. They consist in strengthening buildings and structures; terrain planning, providing a runoff of atmospheric precipitation; on the surfaces of maximum subsidence of the earth's surface, a network of reclamation ditches is being built; water-reducing wells are being drilled , etc.

To develop such measures for each mine, information is needed on the degree of undermining of the earth's surface by the time it was liquidated. In this case, it is necessary to take into account the influence of the reworking on the parameters of the trough of the displacement of the earth's surface. Over the past few decades, coal seams in the Donbass, as a rule, have been mined in a descending order. For this reason, in many cases, the earth's surface was repeatedly undermined before clearing operations were carried out at deeper horizons. On the overlying horizons, coal was mined 50–80 years ago [19]. It must be borne in mind that such situations are not reflected in the regulatory document [8] and require detailed consideration for each specific case.

The environmental consequences of the operation of coal enterprises include gases released into mine workings and degassing wells, and then issued to the earth's surface. It is possible to estimate their approximate number for the entire period of development of Donbass coal deposits, but it is not possible to reliably establish environmental consequences. In addition to gas removed from mine workings by outgoing ventilation jets and captured by degassing systems during the operation of mining enterprises, it was also released directly onto the earth's surface. This had an impact on the safety of operation of ground facilities and the surrounding ecosystem.

The possibility of gas release to the day surface under the influence of mining is confirmed by cases of gassing of residential premises and the formation of cracks above the stopes. During the development of anthracite seams, the gassing of the premises was observed during the cleaning operations at a depth of 80–250 m. The width of the cracks reached 20 cm at a depth of 100 m for cleaning operations [20]. In a number of cases, the sources of methane release to the earth's surface are adjacent seams occurring at a distance of more than 35 thicknesses of the seam being developed [21].

Under the conditions of the liquidation of mines, it is possible to activate the release of gases directly onto the day surface by squeezing them out under the influence of an increasing level of the depression surface of groundwater. In projects for the liquidation of coal mines, it is necessary to provide for measures aimed at the safe operation of facilities in areas of possible gas extrusion.

Conclusion

On the basis of the research conducted, the trends of the processes that determine the environmental consequences as a result of the operation of mines and the change in these consequences after the liquidation of coal enterprises are established. To reliably predict the environmental situation after the liquidation of coal mines, the following circumstances must be taken into account:

1. The result of the operation of coal mines is the extraction of minerals and the associated removal of rock and water from the bowels, emissions of dust and gaseous products into the atmosphere. In addition, there is a change in the relief of the earth's surface under the influence of its underworking by treatment workings and causes a change in the water balance between surface and ground waters. The long-term operation of mines in the Donbass has led to the formation of a quasi-stationary ecosystem.

2. The closure and liquidation of mines caused a violation of the quasi-stationary state of the ecosystem in the regions. The changes consist in restoring the groundwater level with possible flooding of adjacent territories and water breakthrough into the mine workings of neighboring mines that are still in operation. Currently, to prevent such consequences, the operation of dewatering plants of closed mines continues. The time of production of intensive drainage from the workings of closed mines is largely related to the duration of operation of neighboring mines. After the closure of neighboring mines that are still in operation, the environmental consequences are unpredictable. For a reliable forecast of environmental consequences, it is necessary to establish the final parameters of the earth's surface displacement after the cessation of all mining operations in the region under consideration.

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ASSESSMENT CRITERIA AND ECONOMIC RATIONALE FOR THE RECLAMATION OF DRAINED PEATLANDS

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Abstract

From sequestering and storing carbon to purifying water and maintaining a treasure trove of biodiversity, peatlands benefit people, wildlife and the environment in a myriad of ways. And although they occupy only about 3% of the earth's surface, the ecosystem services that peatlands provide and the positive impact they have on our planet more than justify their support and our diligent care for them.

Covering more than 400 million hectares worldwide, peatlands can be found anywhere from high mountains to the sea, from high to low latitudes. They are a type of wetlands - ecosystems with peat soil. Peatlands provide important ecosystem services that contribute to the well-being of people and the natural environment.

The drained peatlands are extremely diverse and heterogeneous in their condition. This is due to the use of different methods of peat extraction, the timing of sites being decommissioned, the state of the drainage system, the type of deposit, the strength of the residual layer of peat and its properties, the properties of the mineral rocks underlying the peat deposit, etc.

When choosing the direction of use of VTR, all the above factors must be considered in a complex manner. Rewetting at least two-thirds of drained peatlands, or 30 million hectares, could help prevent the combined human land-use practices in these areas from becoming a source of net carbon emissions. • Re-wetting of peatlands can significantly contribute to the achievement of ecosystem goals.

Drained peatlands are extremely diverse and heterogeneous in their condition. This is due to the use of other methods of peat extraction, the conditions of the decommissioned site, the condition of the drainage system, the type of deposit, the strength of the residual layer of peat and its properties, the properties of the useful mineral rock underlying the peat deposit, etc.

On the basis of scientific research, materials are presented that confirm the possibility of using produced peat deposits taking into account their natural properties.

Introduction

The drained peatlands are extremely diverse and heterogeneous in their condition. This is due to the use of different methods of peat extraction, the timing of sites being decommissioned, the state of the drainage system, the type of deposit, the strength of the residual layer of peat and its properties, the properties of the mineral rocks underlying the peat deposit, etc.

When choosing the direction of use of VTR, all the above factors must be considered in a complex manner. Let's analyze the value of each of these parameters.

The most important technical requirement for peat extraction from the point of view of further use of the drained peatlands is obtaining a flat surface and a constant depth of the residual layer of peat.

In practice, it is not always possible to comply with these conditions. It depends mainly on the relief of the surface of the underlying mineral bed (geomorphological conditions). In order to leave a fixed depth of the deposit, it is necessary to copy the topography of the underlying layer before completing the peat extraction which leads to the same uneven surface of drained peatlands. The leveling of such peatlands indicates a significant difference in the relief and hydrological regime of individual areas. Development of such deposits is complicated.

When a flat surface is reached, the thickness of the residual layer of peat in individual areas and, as a result, the type, degree of decomposition, ash content, physical and agrochemical properties, and the presence of woody remains differ dramatically.

1. Natural properties of drained peatlands

Currently, peat extraction is carried out mainly by milling and up to 10% by excavator methods, therefore, according to the extraction method, extracted milling fields and extracted peat quarries are distinguished.

The quarries filled with peat, stumps of various shapes, thickets of shrubs and forest, with almost no drainage network, are unsuitable for agricultural use.

The most suitable for agricultural use are the fields after the extraction of peat by the milling method in the form of separate aligned maps with a width of 20-40 м, length of 500 м, separated by frequently operating drainage map and bulk channels. The depth of the map channels is 0,5-0,7 м; gross channels - 2-3 м, and the width along the surface - 5-8 м.

Hydrotechnical structures on bulk channels are stored in different ways. Crossings are suitable for the passage of agricultural machinery, locks and crossing locks require repair or reconstruction.

The strength of the residual layer of peat when used in agriculture should be at least 0,5 м, but this layer is not enough. Different crops require a larger layer: perennial grasses - 0,6-0,65 м; cereals - 0,65-0,7 м; in-row - 0,7-0,8 м, that is, the optimal thickness of the layer should be 0,75-1,0 м.

The residual layer on the extracted t/r is mainly represented by peats of the lowland type, since upland peat is rarely found in the bottom layer.

Lowland peat is characterized by an ash content of 6-18%; degree of decomposition 25-40%, acidity pH 4,5-6,0, high content of nitrogen (1,4-4,0 %) and calcium (1,5-6,5%) and low content of phosphorus, potassium and trace elements. The content of mobile forms of phosphorus and potassium rarely exceeds 10 mg/100 g of soil. Hydrolytic acidity varies between 10 and 60 mmol/100 g of water , the degree of saturation with bases - 50-90%. The majority of lowland type VTRs are characterized by a high content of mobile forms of iron oxides (0,3-1,3 %) and mobile aluminum (0,01-0.2%).

Degraded peatlands must be restored, regardless of the type of deposit and the method of peat extraction, no later than one year after the end of mining operations.

If the areas are not restored immediately, they will gradually become overgrown.

Wood species, shrubs, and grasses quickly appear on the lowland-type VTR. Overgrowth of the upland type begins only 3-4 years after the completion of peat extraction.

Prolonging the term of land restoration leads to a sharp increase in the cost of reclamation. First of all, it is necessary to recultivate the developed areas of the lowland type. Upland type peat deposits and quarries belong to the objects of the second priority due to the high costs of their cultivation.

For drained peat deposits, the normative depth of the peat deposit is established depending on the direction of its further use.

For the use of degraded milled fields for agricultural purposes, the residual layer must be at least 0,5 m; for afforestation, which involves plowing with wrapping of the residual layer under mineral soil, is 0,15-0,5 m(not less 0,3 m for afforestation); for a water reservoir or fish farms should be removed completely, including the bottom deposits (silt, sapropel), since the peat flooded in the reservoir is not only lost valuable organic material, but also a harmful component of the reservoir, since the flooded peat often floats to the surface of the reservoir, forming alloy and contributing to its overgrowth.

The depth of the residual layer is conditional, as it depends on the following factors: hydrological regime, geomorphological conditions, type of deposit, mechanical composition of the underlying mineral rocks, properties of the peat layer (dispersity, moisture absorption and moisture retention capacity).

The depth of the residual layer is largely determined by the availability of nutrients in the underlying layer. If the mineral rocks contain sufficient nutrients, the residual layer can be smaller and vice versa. At the same time, it is necessary to take into account the water permeability of the underlying soils. If the soil is dense, the layer of peat should be larger than on permeable soils.

2. Assessment criteria and ecological and economic rationale of peatlands.

At the stage of designing a peat extraction enterprise, it is necessary to substantiate the criteria by which the direction of use of the drained peatlands is chosen, without which the achieved results will not be effective enough, and the reclamation costs will be useless. The analysis of characteristic features of peat deposits allows to develop criteria and a classifier, by which it is possible to determine to which geomorphological group the peat deposit belongs, and to choose a rational direction of use of the area after production of industrial peat reserves. The classifier includes six criteria: the area of the peat deposit within the zero deposit, the configuration of the boundaries of the peat deposit in plan, the shape of the cross-section, and three criteria characterizing individual sections of the peat deposit: the stratigraphy of the deposit, the average ash content of the peat, the acidity of the peat in the bottom half-meter layer.

It is impossible to determine the geomorphological group of a peat deposit based on only one or two criteria. For example, peat deposits of moraine plains, sewage basins and floodplains can have the same area.

But at the same time, they will differ in configuration in the plan. Peat deposits of moraine plains of shallow interfluvial depressions and slopes of floodplain terraces do not differ in plan configuration, but have different deposit stratigraphy, etc.

The dependence of the sizes of the areas of the peat deposit on the geomorphological conditions of occurrence is unclear. If you classify by only one indicator, objects belonging to different geomorphological groups may be in the same group. There is no clear difference between neighboring geomorphological groups. But the groups that stand from each other in a row by four intervals or more differ significantly (Table 1).

Table 1

The area within the zero deposit t/r of different geomorphological groups

Geomorphological group	Area within zero deposit, ha	
	mnimum	maximum
Drainless between moraine basins of the final moraine landscape	100	800
Buried floodplains	100	1000
Floodplain peat deposits	100	2500
Drainless basins	500	6000
Sewage basins	800	8000
Plavno - priterasni	1000	12000
Slopes of floodplain terraces	1500	12000
Moraine plains	1500	16000
Shallow interriver depressions of the basin type	600	20000
Old year	500	28000
Polish plains	7000	45000

In the case when the area does not correspond to the geomorphological group to which it belongs, preference should be given to the remaining five criteria.

The contours of the peat deposit in plan and the shape of its section acquire characteristic features depending on the geomorphological conditions of occurrence.

On Fig. 1 shows the contours of some t/r drainless basins , the development of which took place in conditions of insufficient mineral nutrition.

The group of t/r drainless basins is characterized by a closed contour in plan with a sharply defined boundary. The cross-section of the t/r of this group is characterized by great depths filled with sapropels , a convex surface of the deposit in several places.

T/r of non-drainage basins formed in conditions of rich mineral nutrition , in contrast to T/r of non-drainage basins formed in conditions of poor mineral nutrition, did not enter the oligotrophic stage, therefore do not have a convex shape, they are characterized by the presence of non-peat remains of lakes (Fig. 1), the area of which in some cases exceeds the area of the deposit. Then the shore of the lake and the borders of the t/r (within the zero deposit) have a common closed circuit.

Drainage between moraine basins end -moraine landscape are distinguished by a smaller area, the presence of pine-downy peat and a much smaller layer of sapropels . The cross-section is characterized by the convexity of the deposit surface only in its central part (Fig.).

T/r sewage basins are characterized by a broken contour, the shores converge to the place of the break. Accordingly, slight slopes of the surface of the deposit and the bottom of the basin, directed towards the gap, are visible on the cross section (Fig. 1). The bottom of the basin has many dips and rises. Depressions are filled with sapropels . The place of narrowing is often a transition to a floodplain or floodplain -interterranean t/r.

T/r of shallow interriver depressions (Fig. 1) were formed in the conditions of weak relief. In the beginning, there were shallow depressions underlain by impermeable rocks. Since the initial cells were shallow, the peat-forming process quickly passed into the oligotrophic stage. These features affected the shape of the cross section. If in plan their configuration is little different from the configurations of most t/r lying on watersheds, then the cross-section is very different with a convex surface and a small depth of the basin.

Boundary configuration and cross-sectional shape of peat deposits of moraine plains (Fig. 1) in general terms, they look like t/r of drainless basins , which were formed in conditions of poor mineral nutrition: they have a closed contour, in the central part they are convex. They differ in the absence of thick lake sediments and are present only in the lowest parts of depressions. Sometimes, instead of sapropels, hypnotic peat is observed at the bottom of the depression .

The territory of the Polish plains (Fig. 1 *)* in plan is a large area, limited by a closed contour of an uncertain shape. A characteristic feature is the smooth surface of the deposit and the mineral bottom . almost no slopes and a shallow depression in the mineral soil.

Fig. 1. Scheme of the possible location of peat deposits (t/r) according to the relief: I- the first supraflood terrace; II - the second floodplain terrace; III - watershed, and - t/r floodplain; o - t/r of the first supraflood terrace; *c*, *d*, *d* - t/r of the second supraflood terraces: *e* - t/r flow-through: *g* - t/r of drainless basins ; from - t/r of sewage basins .

The peat industry uses significant areas of peat deposits, which are transferred to it for temporary use from forest and agricultural land funds. According to the existing regulations, after production, t/r must be returned to former land users in a condition suitable for their further use. The total area of produced peat in Ukraine is about 32,000 ha.

On the territory of Ukraine today there are about 32,000 hectares of cultivated peat areas, most of which are not used in the national economy).

The volumes of reclamation are extremely unstable: 2016 - 657 га; 2017 - 168 га; 2018 - 730 га; 2019 - 114 га; 2020 - 235 hectares.

The peat deposit is an important link of the ecological system. With its drainage, the ecological balance that has developed in the area of its location is disturbed. If the peat deposit is drained for the purpose of peat extraction, the changes in conditions in the ecological system occur for a short period (20-30 years), during which these changes do not acquire critical significance. The use of produced peat deposits lasts much longer, and the failure to implement scientifically based directions for their use can cause a large peak in forest areas, reservoirs (waterlogging of nearby lakes, shallowing and disappearance of rivers) and meadows located in adjacent territories, which is usually several times larger than the area of the deposit rational use could provide a significant amount of forest plantations, marketable fish, and hay for livestock. In general, the developed areas must be returned as soon as possible to their original state, in which they were in ancient times.

Until now, the following main directions of use of VTR have been formed: agricultural , forestry, water management and creation of hunting grounds. For many decades, the choice of the direction of use of VTR was not carried out on a scientific basis, but by voluntary decisions of the authorities, mainly for agriculture, in connection with which the practical use of VTR led to negative economic and environmental consequences. The transition to a scientifically based direction of the use of VTR led to a nature protection direction - rewetting, with justified use of individual sub-farms, afforestation and creation of reservoirs.

The phasing of determining the direction of use of disturbed land should be implemented in the following sequence: - at the stage of development of the construction project of the enterprise, the section "Reclamation of areas after peat extraction " is developed, in which the direction of use is determined based on the materials of exploration of its properties and the conditions of the deposition of the peat deposit VTP, the corresponding depth of the residual layer and, taking into account the ecological and socio-economic condition of the region, develop a project of reclamation of the VTP.

Unfortunately, this sequence is rarely followed leads to negative consequences of reclamation even with the investment of significant funds. For example, according to the data, out of 15,6 thousand hectares that were surveyed and transferred to agricultural enterprises, 6,3 thousand hectares were not harvested at all, and 5,1 thousand hectares were up to 15 c/ha of fodder units, and only on 4,2 thousand ha. hay yields ranged from 16 to 30 c/ha.

The main reasons for the low productivity of agricultural land are the neglect of the genetic features of the VTR. Thus, it is practically impossible to create a favorable water regime for agricultural crops on peat deposits of closed basins or the slope of watersheds: in the first case, the soil is overmoistened, in the second - overdried. Unfavorable for agricultural use of VTP with a residual layer of top peat, due to its high acidity, for neutralization of which it is necessary to apply up to 28 t/ha of limestone materials, which is unprofitable , and a layer of peat underlain by sapropel.

One of the most important criteria for choosing the direction of use of the produced areas is the geomorphological and geological features of the peat deposit, which depend on its water and mineral nutrition and, as a result, the properties and direction of use . For the correct assessment of the economic value and the optimal mode of their use. The most complete quantitative and physicochemical characteristics of peat, its underlying mineral soil and information on water and air properties are necessary.

It must be taken into account that the properties of the residual layer peat significantly differs from the surface layer of peat in its low fertility due to the low content of NPK nutrients necessary for plant development elements. Contact layer. which lies on the mineral bottom. on the contrary, accumulates such a high NPK content, that their concentration is toxic for plants. The bottom layer of peat has unsatisfactory water-physical properties, because there is a sharp difference in water-physical characteristics when passing from the peat layer to the mineral underlying rock, and at the border of these layers, after drying, the capillary bonds break, as a result of which the supply of water from the mineral to the the peat layer and the water regime do not depend on the level of groundwater, but are determined by meteorological conditions.

The thermal regime is not very favorable for the development of plants: peat soils are cold, they are characterized by sharp changes in heat and cold during the day and season.

The residual layer is characterized by weak aeration. The number of pores occupied by air is low (does not exceed 2-6 %) compared to unprocessed peat deposits (37-62%).

The excess layer has low biological activity, which is explained by the content of a significant amount of substances that are not hydrolyzed and therefore inaccessible to microorganisms. With the oxidation of the peat of the residual layer, its components are gradually hydrolyzed, the number of microorganisms increases and, as a result, the peat turns into soil. But this process is very slow.

Taking into account the above facts, it is necessary to preserve a significant part of natural ecosystems and use VTR mainly for rewetting, reservoirs and only exclusively for agriculturalland (pastures, hay meadows or cultivation of crops resist ant to the factors specified in this section).

3. Land reclamation and calculation of their economic efficiency at the design stage

Projects for the reclamation of disturbed lands are developed on the basis of the design task and technical conditions.

In the reclamation project, the technical and economic feasibility of reclamation is established, the type of further targeted use of reclaimed land is substantiated, the scope of work of the technical and biological stages of reclamation is determined, the most rational complexes of machines and equipment are selected, schemes for the formation of dumps and mining and planning works, removal, transportation, assembly are developed and applying a fertile layer of soil to the prepared surface of the dumps. A calendar plan of works is drawn up, summary technical and economic indicators and the estimated cost of reclamation works are developed. If necessary, the reclamation project substantiates changes in the technological process of operating enterprises and other, previously approved, design solutions (location of dumps, their shape, parameters, method of backfilling, technology of removal and storage of the fertile soil layer, etc.).

Design organizations of the Derzhkomzem system, the Ministry of Agrarian Policy, the Ministry of Ecology and Natural Resources, and the Ministry of Education and Science of Ukraine are involved in the design of biological reclamation on contractual terms.

The development of individual sections of the project (extinguishing, development, lowering and reshaping of mine tericons followed by their landscaping) or landscaping projects without performing the work of the technical stage of reclamation is allowed to be carried out by divisions of production facilities with the involvement of specialized organizations on contractual terms or using the recommendations developed by them. For example, the following recommendations for biological reclamation on spent mine sites in the Donbass were proposed by the Donetsk Botanical Garden of the Academy of Sciences of Ukraine, dumps on the territory of the Nikopol Manganese Ore Combine - Dnipropetrovsk State Agrarian University, and overburden dumps on the territory of the Precarpathian sulfur-bearing basin by the Lviv State Agrarian University.

Materials of the technical project are transferred to the customer by the project organization (general designer) in four copies, and to the subcontracting project organization in five copies, except for objective estimates, the number of copies of which must be one more. In cases of execution of certain types of work by subcontracting organizations or land users, the project organization shall provide the customer with one additional copy of objective estimates for each subcontracting organization (land user). Working drawings are issued to the customer in four copies. The technical and working project is issued to the customer in the same number of copies as the working drawings.

projects establish the economic efficiency of costs in the process of agricultural and fishery reclamation, which is determined by the time at which reclamation costs will pay off

$$E_3 = \frac{T \cdot B}{E_r}\text{, years} \quad (1)$$

where T is the amount of costs for the technical stage of reclamation, UAH/ha;

B - the same for the biological stage, UAH/ha;

E_r - annual income from the sale of agricultural (fish) products from the reclaimed (irrigated) area, hryvnias/ha.

The initial data for calculating the economic efficiency of reclamation is used from the following sources:

- costs for the technical and biological stages of reclamation - from the estimate to the project;
- a list of agricultural crops - from the structure of crop rotations in which the plot is expected to be used, or from the crop rotation, if they will be used outside the crop rotation; in the design of the reservoir, the species of fish that will be bred are established;
- costs for the production of a unit of production - from the materials of agricultural or fishing enterprises of the annual reports of farms located near mining enterprises;
- costs for processing and sales of products are estimated to be 7,2% of the total costs of products sold.

The comparative economic efficiency of biological remediation can be calculated as at minimal costs

$$C1 + EnKr = min \quad (2)$$

and for maximum profit:

$$Er - En\ Cr = max \quad (3)$$

where C1 is current costs for each option, UAH;

Kr - capital costs for 1 гaland reclamation, which includes production losses associated with land disturbance, hryvnias;

Er - the total amount of the average annual effect from 1 гaland reclamation, hryvnias;

En - normative efficiency ratio of capital investments.

The technical conditions for the design of reclamation are a document that justifies the choice of use of reclaimed land, determines feasibility and production value, as well as establishes the approximate scope of work, cost and technical indicators necessary for the design of reclamation.

Technical conditions are drawn up at the expense of the founder by the general designer with the participation of project organizations of the system of the Ministry of Agrarian Policy, the Ministry of Forestry , the Ministry of Fisheries, Derkomzem of Ukraine, etc., which are involved as subcontractors in the design of reclamation, agree with the customer and other interested organizations and are approved by the head (deputy) executive committee of the regional Council of People's Deputies.

In the case of land reclamation of the state forest fund , the working project must be agreed with the relevant forestry authorities.

Technical conditions include:

- general conditions about the object of reclamation (location, characteristics and area of disturbed lands, characteristics of soil cover, direction of reclamation, etc.);
- conditions for performing the technical stage of reclamation (requirements for backfilling of sinkholes, planning of dumps, etc.), approximate scope of work, etc.;
- the conditions for the implementation of the dialogue stage of reclamation, the terms of biological reclamation, the type of subsequent use of reclaimed land, including arable land, hayfields, limed slopes, afforestation, greening of tericons, etc.;
- the procedure for carrying out reclamation works and their financing.

In general, recommendations developed by Derzhkomzem, branch ministries and departments can be used when drawing up technical conditions.

At existing mining and other enterprises, before drawing up the technical conditions, a survey of the land plots that are planned to be reclaimed is carried out. For this purpose, a commission is created, which includes representatives of the regional state administration, the Department of Agriculture, the Department of Land Resources, forestry authorities (for the lands of the state forest fund), agricultural enterprises to which the plots of land will be transferred, customers and general designers, on whose initiative the survey is conducted. If necessary, the commission includes representatives of subcontracting organizations, sanitation stations, basin and fish inspection, etc.

The commission establishes:

- the presence of disturbed lands, including those subject to reclamation;

- according to which decision (order), when, for what period, for what purposes and at the expense of which lands were the lands confiscated.

At the same time, the commission agrees on the directions and type of reclamation and enumerates measures that must be carried out at the technical and biological stages of reclamation to protect soils from erosion, waterlogging, chemical melioration of toxic rocks, etc.

The results of the survey are formalized in an act, and their materials are used during the drafting of technical conditions.

The reclamation design task is prepared by the customer (production association) with the participation of the design organization that undertakes the development of the project (general designer), with the involvement, if necessary, of specialized (agricultural and forestry) organizations.

The reclamation design task includes:

- basis for drawing up the reclamation project;

- characteristics of the design object;

- the list of options to be considered on the basis of a technical and economic comparison depending on the complexity and volume of violations, as well as: the value of the violated lands;

- approximate values of the main technical and economic indicators and other data.

Attached to the task is a certificate on the types and number of machines and mechanisms that can be used during reclamation, as well as those that have design and research materials.

During the development of reclamation projects, technical documentation on geological prospecting and other survey works is used, on the basis of which the construction (reconstruction) project of the mine was drawn up, as well as general plans, profiles and materials of additional surveys carried out during operation and after its completion.

In cases where the initial data necessary for the design of reclamation are not available or the initial materials cannot be used, the customer may instruct the project organization-general designer or, on his recommendation, a specialized design or search organization to prepare, under a separate contract, the necessary for the design of reclamation raw materials at the expense of funds of the main activity of the customer enterprise or funds allocated to it for such purposes by a higher authority.

The list of raw data for designers includes:

- brief data on the economy and prospects for the development of the district's industrial and agricultural (forestry) potential;
- requirements of local forestry and agricultural authorities and the sanitary-epidemiological service regarding improvement of land use, preservation or restoration of nature, improvement of sanitary-hygienic conditions, etc.;
- information on the acquired experience and proposals for reducing the negative impact of mining operations on the earth's surface;
- data on positive experience and existing proposals for technological schemes of mineral development, which ensure the most complete extraction of subsoil;
- information on methods of forming internal and external overburden dumps;
- land use plan and land management project of land plots that may be disturbed as a result of the activity of the mining enterprise, or have already been disturbed;
- data on soil grading and economic evaluation of lands to be disturbed by industrial enterprises.

The list of raw data of operating enterprises with disturbed lands includes:

- general information about the enterprise (name, subordination, location with indication of administrative district, region, country);
- the area of the mining concession according to the project of the enterprise (ha);
- land area (ha), including;
- lands of agricultural enterprises (total, including: arable land, perennial plantations, hayfields, pastures, fallows, forests and shrubs, swamps, other lands);
- lands of the state forestry fund (total, including: agricultural land, forests and shrubs, swamps);
- land of other categories (total, including agricultural land, others);
- the total area of disturbed land at the beginning of reclamation design, including outside the boundaries of the registered land acquisition;
- from the total area of disturbed lands (ha) are occupied by: filtration fields, settling ponds and other treatment facilities;
- drinking and technical water reservoirs, industrial sites;
- warehouses of coal and other products, electric substations, pumping stations and other buildings, structures and areas outside the main industrial site;
- rock dumps (total, of which: plate-shaped (flat), dumps of mining enterprises, external and internal dumps, cuttings, hydraulic dumps , ash accumulators, etc.);
- lands disturbed as a result of surface manipulation by underground mining works (total, of them: sinkholes, dry depressions, waterlogged or swampy sinkholes and depressions, areas of the surface unsuitable for use in agriculture (forestry) under the conditions of the formed microrelief (undulations, drops, etc.));
- lands disturbed by open mining (total, of which: quarry excavations, total, including: with internal dumps, residual access trenches, other violations);
- reclaimed land subject to reclamation (total, including the types listed above);
- the number of rock dumps of mining enterprises and their characteristics (total, incl .), which are still in operation, actual and design forms and parameters of the dumps, storage technologies, terms of operation, intensity of erosion processes, lithological composition,

presence of places of burning and heated rocks, for mine areas, data on self-vegetation and greening, development of dumps and removal of rock with an indication of the achieved technical and economic indicators, parameters of the protective zone, the nature of the territories adjacent to the diversion, the possibility of using rocks for filling in dips and depressions, the presence and characteristics of access roads roads;

- a brief description of the special conditions of disturbed lands (waterlogging, flooding, loss of valuable agricultural and other lands, formation of complex cross-country terrain unsuitable for agricultural use, other features).

The raw data of active mining enterprises with disturbed lands include:

- brief mining-geological and mining technical characteristics of the enterprise (geological structure, reserves, characteristics of overburden and sediments, minimum and maximum depth of work, angle of incidence, number of developed layers and their thickness, development system and method of roof management, methods of forming dumps, roof coefficient, volume of mined overburden).

Data are provided regarding:

- general information about the enterprise (name, subordination, location with an indication of the administrative district, region);

- the area of the mining concession according to the project of the enterprise (ha);

- area of land acquisition (hectares), including : land of agricultural enterprises (total, including : arable land, perennial plantations, hayfields and pastures, fallows, forests and shrubs, swamps, other lands);

- lands of the state forestry fund (total, including agricultural land, forests and shrubs, swamps);

- land of other categories (total, including farmland , others);

- the expected maximum area of disturbed lands (by types of disturbances) based on forecasts of disturbance of the earth's surface;

- design characteristics of rock piles (shape, method of formation of piles, parameters, rock composition, number of piles, their location, period of operation, expected volume of rock storage by periods, the possibility of using rock for filling pits, depressions, quarry excavations, etc. .);

- predicted assessment of forms and parameters of surface disturbances during underground mineral development (falls, depressions, etc.) taking into account the work experience of this enterprise and others that are in similar mining and geological conditions, and using the methodological instructions of project institutes regarding the prediction of sizes and the nature of land disturbances, deformation of the earth's surface during underground mineral development to substantiate the scope of reclamation works;

- predictive assessment of other possible violations of land (flooding, waterlogging, drying, etc.);

- measures and proposals for making changes in the mineral extraction technology in order to reduce the areas disturbed in the process of mining operations (leaving rock on the territory of the deposit).

4. Economic justification of the reclamation of produced peat deposits by its afforestation

Reclamation of VTR through its afforestation is one of the world-recognized directions of their reclamation.

When afforesting the VTR, it is advisable to follow the following recommendations.

- Since VTPs are located on the lower parts of the terrain, their forestry use is possible only with high reliability of the drainage network.

- The conditions of forest growth depend on the fertility and strength of the residual layer of peat and the composition of the rocks of the mineral bed .

- Reclamation must be carried out in the first 2-3 years after the areas are decommissioned , before the creation of a powerful grass cover and the natural restoration of the shrubbery (mainly verbolisis - thickets of willows). Overgrown areas require additional labor costs and funds for reclamation during their afforestation.

- Areas on which tree species have recovered well in the amount of at least 20,000 trees per hectare, with their uniform distribution over the area, are included in the forest fund without additional cultivation of crops.

- Natural regeneration of the forest.

- Soil preparation for afforestation depends on the category of the field according to the level of groundwater.

The main condition for the effective use of water resources in both agriculture and forestry is the compliance of the drainage network with their requirements. A dense network of manufactured maps, destroyed map and shaft channels, the poor condition of bridges and crossings, and the presence of a narrow-gauge railway greatly hinder the timely and effective development of the VTR. The complex of measures to put the VTR in order, which are handed over to forestry, includes:

- cleaning of all channels, deepening of roll-overs, giving the bottom of the slopes at least 0.0002 to ensure spontaneous drainage, and slopes - a coefficient from 1.0 to 2.0.

- deepening of each - 6 map channel, which runs along the lowest part of the developed area, up to 1-1,2 м. The distance between the map channels is 150-250 м.

- surface profiling.

repair and construction of bridges, crossing pipes, regulator pipes, pumping stations and cleaning of fire protection reservoirs.

The surface of the VTR is uneven and has ups and downs. The nature of the alternation of relief elements is different: from clear to gradual.

The topography of the VTR surface determines the hydrological and thermal regime of the area, as well as the physical and agrochemical properties of the soil. The heterogeneity of the relief leads to the fact that in the post-flood period, some places are temporarily flooded, while others are not flooded at all. This leads to the fact that crops are planted at different times and often with great delay. The residual layer of peat, depending on the relief, is heterogeneous in terms of capacity, botanical composition, degree of decomposition, and ash content. All these factors have a different effect on the reforestation capacity, the growth of tree species and the development of grass vegetation.

The milling fields of the Russian Federation, which are best suited for afforestation, are divided into 4 categories according to the hydrological regime with a close technological complex of reforestation works:

Fields that *are flooded* , with RHV from +30 in the spring and until - 40 смautumn, as a rule, these are fields where water lowering was carried out with the help of pumping stations. They are often overgrown with cattails. If up to 35% of the area is subject to flooding, they are not suitable for afforestation and can be used for meadows or marshland for wild game. They occur infrequently.

Low fields - with RHV fluctuations from +10 to -60 см. Flooding is observed in early spring on areas less than 25 %. Such areas are common and suitable for afforestation and meadows. The nature of development, agrotechnics of processing and assortment of wood species depend on the duration of flooding of areas. Tractor units are difficult to operate on them, and only crawler tractors and tillage machines of swamp modifications can work. In low fields, it is mandatory to create elevations in the form of rolls, which are poured during plowing of the soil with ditching plows or two-furrow forest plows. Planting is carried out manually in the spring in the ridge of the shaft . Autumn planting is unacceptable, as the plants get wet and die from diseases .

To afforest these fields with well-decomposed peat, spruce, black alder, and to a lesser extent Scots pine are used.

Areas with medium and weakly decomposed peat are afforested with pine and spruce.

Weevils and birches often appear in low fields, which suppress the development of pine, therefore, after 4-5 years of planting, lighting must be carried out. Chemical lightening is carried out in May by spraying with herbicides (4 - 5 kg/ha).

Medium fields - with RHV fluctuations from -50 to -150 см, often developed to mineral soil. They are less common than low fields. Areas with a layer of peat are more 30 смappropriate to use for meadows, the rest - for afforestation. They are cultivated by continuous plowing. If there is turf, it is discusted in two tracks. Plants are planted with SLN-1, SNL-1L, LMD-1, etc. machines.

For afforestation of these fields, it is best to use pine and up to 30% spruce. On fertile soils, the proportion of spruce is increased to 50%. Birch is regenerated here naturally. It is advisable to introduce it in fire protection areas, protective strips.

High fields - with RHV fluctuations from -1,0 to -2,5 м. They occur infrequently. On them, sandy mounds alternate with peaty depressions after peat production. They are not filled with water. In the summer, the peat layer dries out a lot. High fields are planted only with pine or warty birch after continuous plowing or in the bottom of the furrow.

This classification is the basis for the appointment of silviculture measures, the compilation of technological maps and the planning of works on the VTR.

In all fields, it is better to plant in the spring. The approximate planting rate is 7,000 seedlings per hectare. The distance between seedlings in rows is 60 80 см, the distance between rows is 1,8-3 м.

Planned survival after the second year is 70%, seedlings are planted in the spring of the second year.

In order to prevent overgrowth of plantations with foreign plants in the spring, before the soil dries out, it must be treated with herbicides, which ensures the purity of plantations for 2-3 years.

All tree species grow better with a residual layer of peat no more than 20-30 см, which allows the roots to penetrate into the mineral soil and carry out processing that ensures the mixing of mineral soil with peat.

Mixing the residual layer of peat with the bedding layer of mineral pound is the most effective method of soil treatment for forestry development. From this point of view, the peat layer should have a thickness of 5-10 смless than the processing depth. If soil cutters are used for processing, which loosen the soil to a depth of, then the thickness of the remaining 20 смlayer of peat should be 1 0 - 1 5 см. The strength of the residual layer also affects the subsequent growth and development of tree crops. In areas where the peat layer is smaller, the root competition of the tree stand occurs earlier and leads to self-thinning . At the same time, waste occurs rather in dense stands of trees and in areas where the nutrient reserves of the mineral underlying rock are insignificant.

On sandy and loamy soils, it is necessary to leave a layer of peat with a thickness of 15-20 см. For the cultivation of species most demanding of mineral nutrition (poplars, spruces), the layer of peat can be increased to 30 см.

Therefore, it is impossible to name a single depth of the residual layer of peat under forest plantations for all types of plots.

The nature of the underlying soil largely determines the technology of primary, basic and additional soil treatment. Yes, heavy mineral soils do not allow water to pass through, and when they dry out, they harden a lot.

The stratigraphy of the VTR differs not only in individual massifs, but also in small areas of the peat deposit. Lowland deposits are formed mainly on sands, loams , rarely on loams, upland deposits are formed on clays, loams, moraine and calcareous deposits of various thicknesses.

The development of VTR leads to an increase in the degree of decomposition, which improves soil properties and increases nutrient reserves. The intensive decomposition of peat is especially facilitated by sowing perennial lupine (without lupine - by 2 %, *with* lupine - by 5-9%; ash content increases by 0.5% and 1.4-1.9%, respectively).

A sharp transition has a special effect on the development of woody plants:

- from loose peat to strongly compacted mineral soil,
- excessively high humidity to low,
- from light peat to heavy soil.

The roots of many plants cannot always overcome this transition line. This environment can be changed by agrotechnical measures, one of which is the mixing of layers of peat and soil. Significant changes in physical properties (looseness, humidity, etc.) in the upper layer, where the root system of plants is located, require the development of special agricultural techniques, the selection of machines and equipment.

The presence of stumps in peat creates great difficulties in the processing of VTP, increases the wear of the working parts of machines, complicates the movement of aggregates, reduces their productivity.

Depending on the number of stumps in the residual layer, the processing technology is largely determined. Stumps and hardwoods are fragile and easily destroyed during initial processing, so it is not necessary to remove them. Pine stumps are stored well, so they must be removed before forestry development. Only equipment with disk working bodies works normally with high pileness .

Agrochemicals include such properties as absorption capacity, hydrolytic acidity, content of potassium, phosphorus, mobile forms of nitrogen, ferrum Fe^{2+} . With cultivation, by growing a forest, 10 смslight acidification of the soil occurs in the upper layer due to the decomposition of peat with the formation of acids. In the upper 20 смlayer, the content of mobile forms of nitrogen increases, potassium reserves decrease. The presence of ferrum Fe $^{2+}$, toxic for plants, in peat and the underlying mineral layer significantly complicates the cultivation of forest crops . Its content reaches 25.5 mg in 100 гthe soil and prevents the penetration of roots into the depth, weakens the development of plants, and also negatively affects the processes of nitrification and accumulation of mobile phosphorus. Mobile aluminum is also harmful to the root system. Stocks of toxic compounds in the soils of the VTR significantly decrease when moving from overmoistened, low-lying areas to elevated areas, i.e., where aeration is better. At the same time $Fe^{2+} \rightarrow Fe(OH)_2 + Fe(OH)_3$. After mixing the residual layer of peat with mineral soil, it is necessary to apply fertilizers once, in contrast to agricultural development, which replenish the soil with nutrients, stimulate the decomposition of peat components that are not assimilated by plants, and create favorable conditions for microbiological and enzymatic activity of the soil. It is necessary to revive the dead organogenic rock as soon as possible and create conditions for the development of woody species in it.

Natural regeneration of the forest depends mainly on the regime of groundwater, properties of peat, the presence of a source of insemination, etc.

The first 2-3 years of the VTR are not overgrown with woody vegetation, only in some cases willow and birch seedlings appear . Initially, they inhabit low-lying, waterlogged areas that are periodically flooded, and the slopes of the drainage network. Then they spread throughout the massif. In areas that are flooded, the stairs gradually differ in growth. Trees develop best on natural microelevations , the lowered areas are overgrown with reeds, sedges, thistles, etc.

In the elevated areas, recovery is weaker due to the lack of moisture in the upper layers and the wind blowing the seeds to the lower areas . The species composition of self-regenerating crops is very limited: it is mainly downy birch, and aspen, pine, and spruce regenerate much worse. Aspen and spruce grow well in areas with RH from -0.2 to 0,6 м. Pine grows better in areas with a lower level of groundwater, that is, in elevated and medium areas.

A large number of shoots are squeezed out in areas with a deep layer of peat, because in the spring the peat swells up a lot, and with the onset of warm days it shrinks a lot.

In addition, areas with a significant layer of peat become overgrown with grass vegetation earlier and more intensively, which prevents the regeneration of tree species. Therefore, VTP can self-restore, but the assortment of tree species will be quite limited, therefore the main area of the VTP should be subject to cultural afforestation.

Processing soil has a decisive role in the productivity of forest plantations, as it determines the water-physical, air, agrochemical and microbiological properties of the soil. Types of processing include *continuous processing (plowing), creation of micro-elevations and making furrows* .

Continuous tillage changes the layer in which the horizontal roots are located, which make up 90% of the root system.

The creation of micro-elevations in the form of ramparts improves conditions on one part of the area due to deterioration (pits, furrows) on the other and enables crops to overcome the most unfavorable periods (flooding, waterlogging).

Conducting furrows worsens the agrochemical and water-physical properties in the areas and slightly improves them outside of them. It is used where the provision of moisture is crucial in the first years, as their bottom is moistened better than the slopes and ridges of the shafts.

The quality of any type of soil treatment depends on the type of treatment tool.

Soil processing in forestry production is carried out only when creating crops, then natural processes take place.

The following ways of creating cultures are possible:

- process of forest restoration as a result of self-sowing of seeds, but environmental conditions are not always favorable for the emergence of seedlings and their subsequent growth and development;

- sowing pine and spruce seeds 10-12 pcs. in the sowing place. The success of this method is low: in 9 81% there were no ladders;

- the main method of reforestation is planting saplings. It is carried out *manually* or forestry machines. In low places, where micro-rises are created , planting is carried out manually, since it is difficult to move equipment on the prepared soil and there is a high probability of significant damage to the shafts.

The success of forest crops strongly depends on the period of planting. Survival and preservation of plants planted in spring is much higher than in autumn.

The main reason for the loss of plants in low places is wetting and washing of plants (37-64%) and crushing (13-40%). Spruce is best stored here.

Autumn planting of medium and high fields is more successful, but also unsatisfactory in general. Pine seedlings are especially poorly preserved (41-75% loss).

The success of forest crops is evaluated by their survival after planting seedlings and by their growth rates. Their survival depends on the breed, the age of the planting material, the soil category, weather changes, susceptibility to the development of weeds, etc.

On medium and tall one-year-old pine saplings, this indicator ranges from *87* to 100 *%, and* decreases to 53-94% in two-year-olds. High survival rate (90-100 *%)* two- and three-year-old Christmas *trees* and 1-2-year-old *birches* , somewhat lower in *aspen* (48-79%).

In low fields, the survival of one-year-old pine seedlings is: on unprepared soil 89-95%, after plowing - 71-93%, on ridges of shafts 80-87%. Survival of two-year-olds does not exceed 37 - 86%. In *spruce* and *birch, this* indicator is much higher (97-100%), in *black* alder it decreases to 74-98%.

Survival on deep peat is significantly lower than on a mixture of peat and sand.

On areas prone to intensive overgrowth with weeds, large saplings up to 0.4 cm high are used 0,6 м, which allows you to get rid of time-consuming and costly expenses.

In terms of growth indicators, warty and downy birches are the best in low fields.

Pine accelerates growth in height only from the second year, spruce from 4-5, and birch and alder, under favorable conditions, already from the year of planting.

Large pine and spruce saplings tend to get sick after 2-3 years and only then develop normally. Alder, spruce, aspen, poplar, oak suffer from freezing in depressions of middle fields.

Successful development of species that grow quickly and build up a significant mass of roots that bind the peat soil before the beginning of the autumn-winter season. These species include poplar or energy willow (Fig. 2).

Fig. 2. Growth of crops on different VTR: *1* - cultivated peat; *2* - produced edge; *3* - deeply peated areas, low fields; *4* - shallow bottom deposit

From Fig. 2 shows that only on cultivated (processed and fertilized) uncultivated outskirts, shallow areas with favorable aeration, these cultures form highly productive plantations.

The preservation and growth of crops strongly depends on the development of weeds and the application of mineral fertilizers.

Weeds and the dynamics of their growth on different VTPs differ significantly.

The most intensive development of weeds is on *fertile deposits of low fields.* These are Ivan-tea, cypress, thistle thistle , cypress , chernobylnik, etc., which reach a height of 60-80 см, the degree of coverage is 70-100%, and at the same time 8-18 t/ha of green mass is built up, then grasses take root, which after 4-5 years form a solid sod.

Medium and low decomposition the peat is covered with mother-and-stepmother, marsh horsetail, occasionally reed. They develop weakly, so they are not a threat to the development of crops.

There are mechanical and chemical methods of weed destruction.

Among the first, loosening of the inter-rows with cultivators, weeding with hoes, mowing of weeds and their trampling by various means are used. The efficiency of the mechanical method is low.

The best results are observed with the use of chemical agents, including triazine herbicides such as Radokor , Simazine, and Atrazine . When applying 20 кгthe active substance per hectare of soil, they thin out the grass by 80%. Their effectiveness depends on the terms of introduction. The most effective application is before the emergence of weeds.

Application of mineral fertilizers to accelerate forest growth is necessary in connection with the poverty of the peat substrate for phosphorus and potassium.

Application of only nitrogen, potassium and copper-containing fertilizers ($_{60}$ Cu_{12} and N_{60} K_{120}) does not cause noticeable growth of weeds. Superphosphate (N_{60} P_{90} and P_{90} Cu_{12}) and especially phosphorus -potassium fertilizers intensively provoke the growth of weeds, which reduces the squeezing of seedlings, protects them from frost and burns , that is, contributes to their preservation.

A significant acceleration of the growth of forest crops is observed with the introduction of phosphorus -potassium mixtures and various combinations of complete fertilizers, in which the potassium content exceeds the phosphorus content. Already in the first year, growth in height increases by 2-7 times. The best mixture is phosphorus -potassium fertilizers in the ratio of P_{90} K_{120} active substance Fertilizers must be applied to pine and spruce crops that are no older than 5 years and birch trees that are 2-3 years old.

There are various methods of introduction. It is most rational to spread it over the surface of the soil in the spring, before it thaws, since it is possible to use the wheels of tractors during this period . Agricultural spreaders are used (STN-2.8; RTT-4.2; RUM-2; 1-RMG-4, etc.).

5. Economic efficiency of afforestation of the VTR

The main way of developing *low fields* under afforestation there is manual planting of forest crops in ridges and dumps.

From methods of care chemical weeding showed the best results, but even a one-time treatment increases the cost of growing crops by 30%. The involvement of areas covered with shrubs doubles the cost of afforestation. The cultivated areas must be recultivated in the first two years after the completion of peat extraction, before the development of a strong grass cover and before the start of the natural restoration of vermilion.

Labor and money costs can be reduced by combining soil preparation with planting seedlings into one operation. Cultivation of low-lying fields for sown grasses (that is, for agriculture), even with the introduction of significant doses of mineral fertilizers, is relatively inexpensive for farms . And already in the first year, you can get 2-3 tons of hay per hectare, and the labor costs are 14 times lower than during afforestation.

In the conditions of *medium fields,* mechanization of all crop growing processes is possible. Mechanized planting without soil preparation is the most economical . Application of mineral fertilizers in medium doses (P_{90} K_{120}) increases costs by 35%.

The cost of developing these fields under agriculture is approximately the same. But the payback of different methods of afforestation and agricultural use differs significantly: - when growing pine, silvicultural measures are paid for in 8-21 years, spruce in low fields and in fertile areas of the middle strip - in 10-12 years, alder in flowing deposits in 11-18 years, birches in medium and high fields for 17-20 years.

Growing natural birch plantations, which are often formed in low fields, do not require any costs, but their value is always lower than timely planted pine and spruce crops with a payback period of no more than 10 years .

Cultivation of sown grasses in low fields with fertile peat pays for itself within the first year, and with a rotation of crops (3 years) can bring a significant profit. It is even more profitable to grow cereals, even such a low-yield crop as oats.

it is more profitable to use the produced TR with a fertile layer of peat in agricultural production. It is most appropriate to grow pine on fields unsuitable for meadow and field use, prepared for mineral soil and with little decomposed peat.

In areas prone to dense population of birches and willow trees, it is economically expedient to focus on the production of spruce, the cost of labor and money for its cultivation is always lower than for the formation of pine plantations, since silvicultural care and unprofitable lighting are reduced.

For growing poplar, it is better to use shallow areas of middle fields, where grain and row crops give a low yield.

6. Calculation of the ecological and economic assessment from the rehabilitation of the developed areas under the water

management direction

In the conditions of a market economy, Ukraine must have an effective policy for managing its national wealth. Land resources are one of such riches. The current state system of land management of Ukraine at the international, national, and regional levels needs improvement. Careless treatment of land resources, as an object of capital formation, a tool of work and a means of production, leads to a decrease in the future income of the state and the economic, social, and ecological benefits of the country's population.

The main issue of today remains the issue of restoration of exhausted lands by mining enterprises of the region, i.e. bringing them to a state suitable for further use.

Exploitable lands lose their original value at almost every technological stage of mineral development. The initial and final value of the land plot does not correspond to the real market value according to the main indicators of the condition, and depending on the complex of factors is overestimated, or vice versa - below the real value.

Reclamation of produced peatlands is an important reserve for increasing agricultural land. However, during their development, it should be taken into account that they differ significantly from undisturbed soils in terms of their physical and chemical-biological properties. For example, it was established that there are very few easily soluble phosphorus compounds in the residual natural layer of peat . Even less exchangeable potassium. Despite the significant reserves of total nitrogen, in the absence of mobile forms of this element, the peat layer of the production may turn out to be barren. Weak aeration, the presence of oxidizing compounds of aluminum and iron, underoxidation of organic residues leads to suppression of many microbiological processes.

In the process of reclamation of produced peatlands, the thickness of the natural layer of peat, the amount of organic matter in it, and, ultimately, its productivity, must first be determined. According to the existing recommendations, in the case of completion of peatland production, it is necessary to leave a layer of peat at least 50 см.

Practically all peatlands are overmoistened due to groundwater, therefore land reclamation is an important condition for increasing the fertility of the lands on them. Usually produced peatlands are drained in small areas (as they are produced), independently or connected to adjacent reclamation networks.

The development of produced peatlands should be undertaken immediately after the end of peat production and the completion of land reclamation. During primary processing, plowing, disking, milling and rolling are carried out.

Produced peatlands by milling and machine-forming methods of peat extraction should be returned to land users for use in hayfields, pastures, afforestation and irrigation. For this purpose, a drainage network is arranged, the surface is planned, and roads are built. Peatlands produced by the hydro-method are usually reclaimed for fishery use. On them, stumps are uprooted and removed, a drainage network is planned and laid. In Germany, there is a technology for the renaturalization of bogs and peatlands.

There is a distinction between mining and biological reclamation.

The preparatory stage includes: survey and typification of disturbed lands and lands subject to disturbance; study of the properties of overburden rocks and their classification regarding suitability for biological reclamation; determination of directions and methods of reclamation; preparation of feasibility studies and technical work projects for reclamation.

The mining engineering stage involves the implementation of works on the preparation of land vacated after the mining development of deposits for further targeted use in the national economy. During this period, enterprises or production facilities that carry out the development of deposits perform the following works:

- selective removal, storage and preservation of overburden suitable for biological reclamation, including the fertile soil layer;
- selective formation of overburden rock dumps;
- if necessary, planning and covering the planned surface with a layer of fertile soil or potentially fertile overburden;
- backfilling and planing of deformed surfaces;
- arrangement of access roads;
- remedial measures.

The biological stage of reclamation is performed after the mining stage and includes measures to restore the fertility of disturbed lands, aimed at the reproduction of flora and fauna.

Biological reclamation is carried out by land users, to whom lands are transferred after mining technical reclamation at the expense of enterprises and organizations of the relevant ministry, which carried out mining operations on the lands.

The directions of reclamation determine the final use of disturbed lands after carrying out the relevant mining, engineering and construction, hydrotechnical and other measures, they are chosen on the basis of a comprehensive accounting of the following factors:

- natural conditions of the field development area (climate, soil types, geological structure, vegetation, animal life, etc.);
- the state of the disturbed lands before the reclamation (character of man-made relief, degree of natural overgrowth, etc.);
- mineralogical composition, water-physical and physico-chemical properties of rocks;
- agrochemical properties (content of nutrients, acidity, presence of toxic substances, etc.) of rocks and their classification according to suitability for biological reclamation;
- engineering-geological and hydrological conditions;
- economic, socio-economic, ecological and sanitary-hygienic conditions;
- the service life of reclamation lands (possibility of repeated violations and their periodicity).

In the process of choosing the direction of land reclamation, it is necessary to keep in mind that the reclaimed lands and the territories surrounding them - after the completion of the works, represent an optimally formed and ecologically balanced landscape area.

The choice of the type and direction of reclamation is determined by natural and economic conditions and, in most cases, is dictated by which lands were disturbed in the process of mining and how they were previously used.

For example, it is not possible to approach the choice of the type of reclamation in the same way, if fertile chernozems and low-humus, structureless podzolic or sod-podzolic soils are disturbed by the development of deposits. So, the very basic characteristics suggest to a large extent what decisions need to be made. Indicators such as the degree and type of salinization, the level of soil and subsoil water, the method of field development, etc., can provide similar assistance when choosing the type and direction of reclamation.

The effectiveness of reclamation largely depends on the timing and quality of its implementation.

The effectiveness of reclamation largely depends on the timing and quality of its implementation. At the same time, it should be taken into account that the responsibility for timely mining reclamation and the transfer of lands in proper condition, which became vacant after the completion of raw material extraction operations, rests with the heads of mining enterprises, and for timely and rational use - with the land users to whom the rehabilitated lands are transferred.

Studies show that the reuse of reclaimed land can be rational and effective only in the case of the correct choice of the direction of restoration works on disturbed lands. This approach makes it possible to later recreate the disturbed landscape and partially or completely restore the flora and fauna lost in the process of mining development. At the same time, it is necessary to take into account that bringing disturbed lands into a state suitable for reuse may not always coincide with their previous purpose.

Thus, the correct choice of the direction of reclamation should provide for a single goal - the rational reuse of disturbed lands in the national economy.

After conducting a field survey of one of the fully developed and rehabilitated plots, we concluded that no more than 10% of the rehabilitated land is used for agricultural production by the population of the surrounding villages. Advantages in use are given to elevated areas along bulk channels, or on the outskirts with low peat capacity.

The measures envisaged by the reclamation projects aimed at maintaining the necessary water regime of the reclaimed lands do not have the expected effect. Drainage system without maintenance quickly fails, this is facilitated by large settlements of beavers, which build dams on canals. Lands are returning to their natural state - overgrown with swamp vegetation.

Therefore, after analyzing the inefficiency of the use of reclaimed land, I want to propose a water management direction of reclamation. It envisages the use of pits and other man-made depressions for various reservoirs, including fish ponds. Therefore, it will allow not only to restore the cultural landscape, but also to bring additional income to the enterprise.

Requirements for land reclamation in the water management direction should include:

- Creation of reservoirs for various purposes in pits, trenches, deformed areas of mine fields;
- Complex use of reservoirs mainly for water supply, fishing and recreational purposes, irrigation;
- Construction of appropriate hydrotechnical structures necessary for flooding pits and maintaining the estimated water level in them;
- Measures to prevent landslides and erosion of reservoir slopes;
- Shielding of toxic rocks, beds and sides of reservoirs and formations prone to spontaneous combustion in the zone of variable level and above the water level;
- Protection of the bottom and shores from possible filtration;
- Measures to prevent acidic or alkaline groundwater from entering reservoirs and maintaining a favorable water regime and composition in accordance with sanitary and hygienic standards;
- Measures for the improvement of the territory and greening of the slopes.

Table 2

Technical conditions for reclamation

The name of the object	Peat bog
1	2
Purposes of the reclaimed area.	Reclamation under the reservoir of technical water with the creation of a green zone around it for fishing activities.
The thickness of the removal of the fertile layer of the soil, the place of its storage or transportation for the improvement of unproductive lands.	Remove the vegetation layer on the uncultivated area of the quarry with a thickness of 30 cm, with further use to create a green zone around the reservoir.
The thickness of covering the reclaimed area with a fertile layer of soil.	According to the volume of the laid soil.
Construction of access roads to the reclaimed site.	Use existing driveways.
Term of completion of mining reclamation works.	The reclamation work should be completed within a year after the deposit has been worked out.

7. Economic evaluation of the expediency of land reclamation

Environmental conditions of disturbed lands largely determine the amount of restoration work and costs on their implementation, technology and directions of reclamation.

However, in the economic evaluation of the costs of reclamation aimed not only at the reproduction of natural resources, but also at meeting public needs as a natural environment, it is necessary to take into account both its results (economic and socio-ecological), as well as the factors that determine them.

The role of socio-ecological factors characteristic of disturbed and rehabilitated areas, as well as the area of their location, in the economic evaluation of reclamation is manifested in the form of their influence on the value of economic indicators (costs and results), the choice of optimal directions and technological schemes of reclamation in each of the areas objects

As one of the types of economic activity, land reclamation (unlike other production processes) does not bring profit to the enterprise , but is characterized by costs.

Costs for the technical stage are calculated based on the volume of work and specific costs, determined on the basis of uniform district unit prices for earthworks and other types of work or according to costing, which is summarized by cost elements.

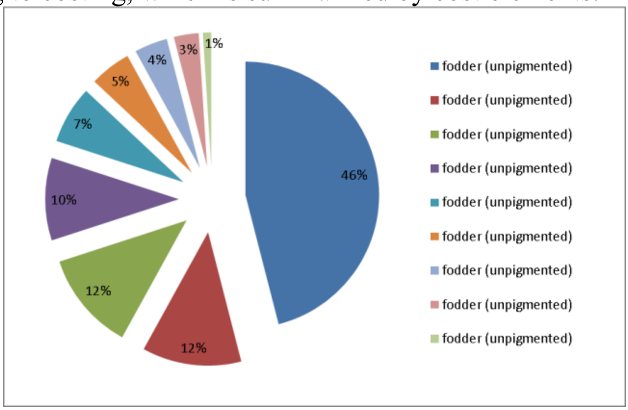

Fig. 3. Diagram of the distribution of costs for the water management method of reclamation

According to Vlasov VA, the production of fish products is characterized by high productivity compared to other products containing animal proteins. Capital investments for the production of 1 ton of meat are almost four times more than for the production of 1 ton of fish products.

From 1 hectare of reservoir area only due to natural fish productivity, 2-3 centners of fish products can be obtained annually, that is, approximately the same amount of meat that can be obtained by grazing cattle on high-quality natural pastures. When feeding, you can get 10 times more fish.

Costs for the mining and technical stage of reclamation per 1 ha in the water management direction are UAH 8,104.

Let's calculate the costs for the mining stage for the creation of artificial ponds according to formula (4):

$$V_{gr/z} = V_g * \left(S_{oz} + S_{forest}\right) \qquad (4)$$

where $V_{gr/z}$ - costs for the mining stage for the creation of a recreation area

Vg – costs for 1 ha of mining reclamation

S_{oz}- the area of the lake

S_{forest}- the area of forest plantations

$$V_{gr/z} = 16{,}22 * 8104 = 13144688 UAH$$

To launch in the reservoir, it is assumed to buy fry of carp, crucian carp , white carp weighing 20-30 grams/piece, price 20 UAH/kg, delivery 3.5 UAH/km (30-40 kg is assumed for 1 ha of the reservoir. ufry).

Let's calclate the costs of stocking the lake with fish according to formula 5

$$T_{smal} = C_{kg} * S_{oz} * P_{mal} \qquad (5)$$

where T_{smal} is the cost of the required amount of fry to launch into the lake

C_{kg} - the number of fry for launching per 1 ha of reservoir

S_{oz} - the area of the lake

P_{mal}- the cost of 1 kg of fry.

T_{smal}= 40*16*20 = 12,800 UAH

Costs for the delivery of fry per 1 km - UAH 3.80 for a distance of 100 km, in this way we will pay for delivery:

D = 100*3.80=380 UAH.

30 hryvnias are needed to populate 1 ha of the lake with plankton. for the settlement of 16 hectares of the lake - 480 hryvnias, costs for the purchase of fry are 12,800 hryvnias, costs for delivery - 380 hryvnias. therefore, we can calculate the costs for the biological stage of lake reclamation (6)

$$V_{boz} = V_{pl} + T_{smal} + D \tag{6}$$

where V_{boz} is the cost of the biological stage of lake creation

V_{pl} - spending on plankton

D - transportation of fry

T_{smal} - the cost of the necessary amount of fry to launch into the lake

$$V_{boz} = 480 + 12800 + 380 = 13660\ UAH$$

Thus, the costs of creating a recreation area will be

$$V_{r/z} = V^{g}_{r/z} + V^{b}_{r/z} \tag{7}$$

where Vr /z - costs for creating a recreation area

$V^{g}_{r/z}$ – total costs for the mining and technical stage of reclamation

$V^{b}_{r/z}$ - total costs for the biological stage of reclamation

$V_{r/z}$=34126.88+ 13660 = 47786.88 hryvnias.

The future profit from the recreation area 1 year after the opening of the area was calculated. Profit from the sale of fish - UAH 26. - 1 kg, there are 700 individuals in our lake, therefore:

Year = 26·700=18,200 hryvnias.

Thus, the profit in a year will be UAH 3,704,000. with expenses for the creation of a recreation area 5956412.88 hryvnias. Comparing costs and profits, we can say that more than half of the invested money will be returned already a year after the opening of the zone. Thus, in the third year of creation of the recreational zone, the costs will be fully paid off and the zone will bring profits.

Conclusions

On the basis of scientific research, materials are presented that confirm the possibility of using produced peat deposits taking into account their natural properties.

1. The main areas of use of VTR: agricultural, forestry, water management and creation of hunting grounds. For many decades, the

choice of the direction of use of VTR was not carried out on a scientific basis, but by voluntary decisions of the authorities, mainly for agriculture, in connection with which the practical use of VTR led to negative economic and environmental consequences. The transition to a scientifically based direction of the use of VTR will lead to a nature protection direction - re-wetting, use of separate areas for agriculture, afforestation, creation of reservoirs, cultivation of energy willow.

2. The phasing of determining the direction of use of disturbed land should be implemented in the following sequence: at the stage of development of the enterprise construction project, the section "Reclamation of areas after peat production" is developed, in which, based on the intelligence materials of its properties and the conditions of the peat deposit, the direction of use of VTP is determined, appropriate the depth of the residual layer and, taking into account the ecological and socio-economic condition of the region, develop a project for the reclamation of the VTP.

3. The main reasons for the low productivity of agricultural land are the neglect of the genetic features of the VTR. Thus, it is practically impossible to create a favorable water regime for agricultural crops on peat deposits of closed basins or on the slopes of watersheds: in the first case, the soil is overmoistened, in the second case, it is overdried. Unfavorable for agricultural use of VTP with a residual layer of top peat, due to its high acidity, for the neutralization of which it is necessary to apply up to 28 t/ha of limestone materials, which is not profitable , and a layer of peat underlain by sapropel.

4. A substantiated ecological and economic evaluation of the rehabilitation (reclamation) of the developed areas and corresponding calculations of the ecological and economic feasibility of implementing the rehabilitation of the VTR are given.

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CULTIVATION OF ENERGY CROPS IN LINE WITH SUSTAINABILITY

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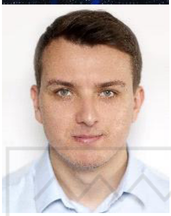

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Abstract

The research objective of this paper is to answer the question of whether obtaining energy from biomass is consistent with sustainable development indicators. A new direction of regional policy was proposed, which is the cultivation of energy crops. The demand for clean energy is now a key global issue where global ideas are being implemented through local action. Drawing on a global sustainability science and practice perspective, we provide the use of biomass for energy purposes, justified through the analysis of three selected indicators of the pillars of sustainable development: the exposure of the urban population to the excessive effects of PM10, eco-innovation, greenhouse gas emissions in CO_2 equivalent. Using these indicators, we found that the cultivation of energy crops is consistent with the objectives of sustainable development and gives the opportunity to activate the rural society. The use of biomass for energy purposes enables the achievement of eight goals belonging to the three pillars of sustainable development: goal 2 zero hunger; goal 3 good health and well-being; goal 7 affordable and clean Energy; goal 8 good jobs and economic growth; goal 9 industry, innovation, and infrastructure; goal 10 reduced inequalities; goal 12 responsible consumption and production: ensure sustainable consumption and production patterns; goal 13 climate action: take urgent action to combat climate change. The improvement in the economic situation of the inhabitants of rural areas can be seen in additional employment in the alternative energy sector. It is shown that a compromise in achieving the SDGs is possible by putting in place an appropriate energy policy that reconciles the interests of economics, ecology, and man. We conclude our paper by discussing the results of our research and their implications for the country's environmental and energy policies.

Keywords: Biomass, Sustainable Development, Renewable Energy

1. Introduction

The concept of sustainable development comprises a global approach to economic, social and environmental phenomena combined with identification of interrelations between them, the choice of developmental priorities when the economic, environmental, and social criteria are applied, as well as treating the natural environment as an entity that evolves and is subject to changes (in most cases anthropogenic changes) [1]. The crucial thing is to preserve natural assets (natural capital) as they are, or even to improve their status. A major problem of the modern society is the actual implementation of the sustainable development strategies that have been promoted by scientists, environmentalists, and politicians during scientific conferences and meetings held all around the world. The most important factors affecting such strategies are: environmental protection, economics, and sociology, while their main goal in the last decades has been the harmonisation of these factors [2,3]. For this goal to be achieved, the public must firmly embrace the concept of sustainable development [4].

We are fascinated by technical progress, we proudly look into the future, mastering and transforming the Earth and nature. The possibilities of technology have no limits, and the implementation of new ideas is only a matter of time. We see wildlife as something that can be tamed, mastered, and exploited. This approach has brought us enormous benefits, but we are already losing our balance. We need a planetary impact constraint model. The steps to be taken must be comprehensive and system-wide. Sustainable coexistence with nature has become our only option. We cannot cross borders. We need to stop and reverse climate change, stop greenhouse gas emissions, stop the overuse of artificial fertilisers, stop grabbing more land for agriculture, stop ozone depletion, stop freshwater consumption, air pollution, and ocean acidification [5]. Nature will benefit from this and we will benefit from it because it is due to nature that the earth's environment is stable. Sustainable development in all areas should be our main goal.

2. Energy from renewable sources

The primary goals of EU climate and energy policy are improving energy efficiency and increasing the share of renewable energy in the total energy balance of the European Union. Every country's energy policy is based on the strategy of balancing the safety of energy materials supply, effectiveness of economic processes and environmental protection.

Energy from renewable sources means energy from natural processes, and energy produced from non-fossil energy sources. The reserves from these sources complement each other in natural processes, making them inexhaustible [6]. The European Green Deal [7], which provides guidance for a sustainable eco-friendly transformation, plans that by 2050 Europe will become the world's first climate-neutral continent. With the forecast that energy consumption will continue to grow, the energy sector needs to be reoriented in such a way as to cover demand and minimise the adverse impact on the climate. The development of alternative energy technologies provides energy stability to the country because of the diversification of energy producers' offers.

Biofuels are divided into gaseous, liquid, and solid. Gaseous include biogas, obtained in the process of anaerobic fermentation of biomass, which consists mainly of methane. Wood gas, which is produced in the wood gasification process, is also a biofuel. Liquid biofuels include biodiesel, bioethanol, methanol and butanol, and vegetable oil.

Solid biofuels are all types of processed and unprocessed biomass that are used as fuel to produce heat or electricity. Biofuels include firewood (chips, wood briquettes, pellets and forest waste, shavings, sawdust), charcoal, energy crops (fast-growing trees, perennials, perennial grasses, cereals grown for energy purposes) and organic residues from agriculture and horticulture (e.g. horticultural production, animal waste, straw) [8]. Biodegradable fractions of municipal waste and peat (dried and possibly briquetted) are also considered to be solid ecological fuels.

The energy production of biomass is decentralized and does not require the construction of power lines. In comparison to the energy produced using conventional methods, it supports economical water management. The production costs of biomass energy are comparable to the costs of producing electricity from the power grid. It should be pointed out that in the poor and developing countries it allows one to improve hygiene and health conditions through the cessation of spilling fecal matter directly onto the fields, which has once been a cause of dangerous diseases epidemics.

There are not many flaws in this kind of energy production, but they are significant. The calorific value of biomass is two times lower than that of hard coal. Biomass processing installations are capital-intensive investments (high investment costs during the construction phase). Furthermore, it is necessary to strictly follow the fermentation regimes (temperature, acidity, and hermetic conditions during the processes). The biomass is usually highly moist which causes problems during its transport and storage. Bio-fuels production requires higher capital expenditures in comparison to the fuels produced during oil processing. Additionally, there are no tax exemptions for the producers of biomass energy [9, 10].

Below is an analysis of the implementation of the assumptions of selected indicators of the social, economic, and environmental pillars by the energy sector based on biomass.

3. The research methods

We used representative indicators for each pillar we had selected. The selection of indicators was dictated by the following criteria: the indicator should show everyday life in regional social policy, achieving the indicator has a measurable impact on improving the condition of the environment, i.e. regional environmental policy. The analysis of a selected indicator reflects one specific aspect of a broader sustainable development goal. We decided to choose these indicators, which are achieved directly or indirectly in energy policy, particularly in renewable energy. We analyzed all the sustainable development goals and showed which goals can be achieved thanks to the implementation of the selected indicator. The research was conducted using the following methods: an examination of documents, an examination of individual cases, analysis, and logical construction. The research technique consisted of observation and analysis of documents.

4. Implementation of pillars` indicators

4.1. Implementation of social pillar indicator

Indicator: the exposure of the urban population to the excessive effects of PM10 (domain: public health) is shown by the annual weighted average concentrations of PM10 at urban background stations located in agglomerations. Particulate matter is a mixture of very small solid and liquid particles, composed of organic and inorganic compounds. Contaminants in the air have a negative effect on human health, causing many respiratory and circulatory problems. Despite the actions taken to reduce PM10, exceeding the standards is one of the most important air quality issues in Poland. Out of 46 zones subject to air quality assessment in Poland in terms of average 24-hour PM10 pollution, exceedances of the admissible level were found in 38 zones. In most zones the limit values for PM10 and PM2,5, and benzo(a)pyrene are exceeded [11].

Biomass contains on average four times more oxygen compared to thermal coal and twice less carbon, but also less sulphur, nitrogen, and ash (on average 5 to 10 times less depending on the type of biomass). Moreover, it is characterised by a high volatile matter content (65-80%) and high reactivity that determine the need to use appropriate technical solutions guaranteeing its energy-efficient processing. The consequence is a higher proportion of emitted PM10 and PM2.5 particles, however, biomass fly ash contains significantly less metal atoms (Ti, Al, Fe) in the elemental composition than coal fly ash [9]. On the other hand, when burning biomass much more charcoal is released into the atmosphere than when burning conventional fuel [12,13].

Thanks to the implementation of the indicator: the exposure of the urban population to the excessive effects of PM10, the following goals can be achieved: goal 3 good health and well-being: ensure healthy lives and promote well-being for all of all ages; goal 13 climate action: take urgent action to combat climate change (Fig. 1).

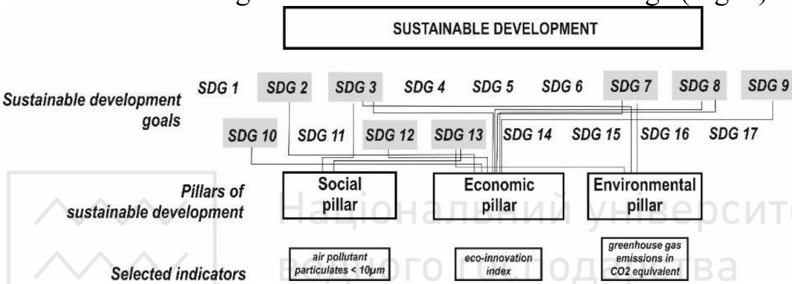

Fig. 1. Implementation of sustainable development goals through the use of biomass as an energy source

4.2. Implementation of economic pillar indicator

Indicator: eco-innovation (domain: innovation) is based on 16 indices from five areas: three of them directly relate to eco-innovation. These are: inputs, activities, and results. The other two groups of indices are the effects of introducing eco-innovation: environmental and socio-economic effects. Innovation means a new or significantly improved product, process, organisational or marketing method, which bring environmental benefits compared to alternative solutions. Innovation is strongly linked to sustainable development. Eco-innovation slows down the exploitation and use of natural resources and the release of harmful substances into the environment. They benefit the economy by increasing the competitiveness of enterprises.

An example of an eco-innovation process is the use of biomass in energy production. By using biomass in the power industry we prevent waste of food surpluses, manage production waste from the forestry and agricultural industries, and dispose of municipal waste

[11]. However, Poland is one of the least eco-innovative countries in the European Union: in 2018 our country was ranked only 26th among 28 countries in the Community [14].

Thanks to the implementation of the indicator: eco-innovation, the following goals can be achieved: goal 2 zero hunger: end hunger, achieve food security and improved nutrition, and promote sustainable agriculture; goal 7 affordable and clean energy: ensure access to affordable, reliable, sustainable and modern energy for all access to clean fuels and technologies for cooking; goal 8 good jobs and economic growth: promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all; goal 9 industry, innovation and infrastructure: build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation; goal 10 reduced inequalities: reduce inequality within and among countries the Gini coefficient; goal 12 responsible consumption and production: ensure sustainable consumption and production patterns (Fig. 2).

4.3. Implementation of environmental pillar indicator

Indicator: greenhouse gas emissions in CO_2 equivalent determine total annual man-made greenhouse gas emissions in relation to the base year 1988, in accordance with the Kyoto Protocol. The Kyoto basket en-compasses the following six greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and F-gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Greenhouse gas emissions are defined as the aggregated emission of the six greenhouse gases listed, weighted by global warming potentials on a 1988 basis equal to 100 [15]. The carbon dioxide equivalent shall be 1 Mg or an amount of another greenhouse gas equivalent to 1 Mg of carbon dioxide calculated using global warming potentials, e.g. one tonne of methane corresponds to 25 tonnes of CO_2. The Kyoto agreement is considered one of the first steps of the international community toward formalised action for effective environmental protection. After the ratification of the Kyoto Agreement, Poland adopted several documents and implemented new regulations on energy development and climate protection, such as th Polish Energy Policy until 2030 [16], the National Energy and Climate Plan 2021-2030 [17], th Polish Energy Policy until 2040 [18] and th Polish Energy Policy until 2050 [19].

Thanks to the implementation of the indicator: greenhouse gas emissions in CO_2 equivalent, the following goals can be achieved: goal 3 good health and well-being: ensure healthy lives and promote well-being for all of ages; goal 7 affordable and clean energy: ensure access to affordable, reliable, sustainable and modern energy for all access to clean fuels and technologies for cooking; goal 13 climate action: take urgent action to combat climate change (Fig. 3).

5. Conclusions

The main objective of energy policy is to ensure the country's energy security, to increase the competitiveness of the economy and its energy efficiency, and to protect the environment.

The use of alternative energy sources can be a good solution in the situation of a huge ecological crisis in the world. Biomass is the most widely used unconventional energy source in the world. This is an opportunity to improve the condition of the environment. The strategy highlights that improved energy efficiency will reduce dependence on energy imports, reduce emissions, and drive jobs and growth, especially in a rural environment. The improvement of the economic situation of the inhabitants of rural areas can be achieved by providing additional employment, which is the cultivation of energy crops.

Preserving the natural capital at the current or higher level is possible by implementing in place an appropriate environmental and energy policy of the country.

The analysis of selected indicators of sustainable development showed that thanks to the use of biomass as an alternative source of energy, it is possible to achieve as many as eight goals: zero hunger; good health and well-being; affordable and clean energy; good jobs and economic growth; industry, innovation, and infrastructure; reduced inequalities; responsible consumption and production: ensure sustainable consumption and production patterns; climate action: take urgent action to combat climate change.

A very important element of the pro-ecological regional policy is the information and education campaign for society. The implementation of sustainable development indicators must be rooted in social consciousness, as environmental education is a factor of fundamental importance for environmental protection and preservation for future generations.

Sustainable development in the energy sector means finding a conflict-free relationship between the social, economic, cultural, and natural aspects of energy generation technology. Poland has one of the largest potentials for renewable energy resources in the EU. In order to be able to use it, it is necessary to increase financial outlays on research and development of technology and create a system of co-financing projects. Actions should be modeled on the European Union, which has been supporting the development of renewable energy sources for many years.

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Conflict of interest statement

The authors declare no conflict of interest.

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AN ANALYSIS OF THE SYSTEMATISATION OF THE GLOBAL ENERGY AND ENVIRONMENTAL USE OF BIOMASS

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Abstract

The work is devoted to work out the technology of power usage of biogas, received as a result of anaerobic fermentation of biomass with the purpose of reducing fossils fuels consumption and greenhouse gases emission. The analysis of power biomass usage technologies in Ukraine has been made, the ways of solution of ecological problem greenhouse effect emergence and climate change connected with it have been formulated. The regularities of the influence of excess air on the environmental and thermal performance of the boiler were revealed, and the effects that occur when combusting mixtures of natural gas and biogas in different proportions were established. For the first time, the indicators of harmful emissions during the combustion of biogas in steel water heating boilers of low power, depending on the mode and design of the boilers, were determined.

Key words: the biogas, the heat generator, the greenhouse gases emission, the biomass, ecological efficiency, the economy of fuel, the harmful emission.

Introduction

The scientific novelty lies in the fact that for the first time a mathematical model of efficient use of biomass energy in the global energy sector has been developed and substantiated, which allows choosing a rational layout of power equipment, determining the optimal structure of consumed energy resources and the cost of generated energy.

The aim of the study is to create scientifically sound technologies, methods and means of improving the energy and environmental safety of hot water boilers that use bioenergy fuel for heat production, while developing scientific and methodological foundations for the environmental efficiency of energy use of biogas obtained from anaerobic digestion of biomass, based on the indicator of specific reduction of greenhouse gas emissions $k_{\mathrm{CO_2}}$

Consumption of various types of energy is the basis for the existence and development of modern society. The continuous growth of production in modern society leads to an increase in energy consumption and, consequently, to an increase in the consumption of fuel and energy resources, which are further converted into heat and electricity.

Energy can be obtained both from non-renewable sources (coal, oil, natural gas, peat, nuclear energy) and from renewable sources (biomass, solar, wind, wave, geothermal energy).

The use of methods of biological conversion of organic waste to produce gaseous or liquid fuel is very promising at the moment. It allows solving not only the energy problem, but also the economic and environmental one, that is why it attracts attention of ecologists, power engineers, economists, and biotechnologists. It is very significant for agriculture, where there is a lot of organic waste. Perspective raw materials in bioenergetics are also wastes from food, microbiological, wood processing industry, waste water from public utilities.

The modern energy consumption is mainly reduced to the use of natural (primary) fuel and energy resources, such as fossil fuels and products of their processing (motor fuel, mazut) and nuclear fuel. This is mainly due to the relatively simple process of obtaining these fuels with their high energy potentials.

The most important factor affecting the energy and economic situation both in the world at large and for Ukraine in particular is the significant increase in energy prices, particularly natural gas. In this connection, the task of finding alternative sources of energy is becoming even more urgent.

As we know, the main energy consumers are industry, power and transport [1,2,3], and it is necessary to take into account that they consume a huge amount of primary resources in the form of solid, liquid, gaseous fuel and air oxygen, they return into the environment a significant amount of gaseous and solid pollutants.

One of the most important environmental issues at present is climate change. This has to do with the impact that this phenomenon is having on people's lives at present and in the foreseeable future. For example, in Ukraine alone, not to mention the world as a whole, the number of negative natural phenomena associated with climate change between 1997 and 1999 exceeded 20 [1]. The increase in average atmospheric temperature over the last 120 years has been 1÷1,2 °C [1,3], and a further warming of 3-5°C [2] is predicted in the XXI century. The main cause of this phenomenon, according to most experts, is the greenhouse effect caused by increased concentrations of greenhouse gases (CO_2, CH_4, N_2O, and others) in the earth's atmosphere.

In order to prevent and slow down the global warming process, the "Framework Convention on Climate Change" was developed in Rio de Janeiro in 1992, containing proposals for an inventory of greenhouse gas emissions and development of national plans to reduce them. In December 1997 in Kyoto (Japan) the Protocol of the Conference of the Parties of the Convention on Climate Change, which proposed specific mechanisms to reduce greenhouse gas emissions, was adopted. Ukraine ratified the Kyoto Protocol on 4 February 2004. It entered into force on February 16, 2005 [1,3-6].

Analysis of anthropogenic sources of greenhouse gases in Ukraine (fig. 1), [1,2] not to mention the world as a whole, shows that fossil fuel combustion for energy production constitutes a significant proportion of total emissions and determines the overall level of greenhouse gas emissions.

Thus, energy saving and replacement of fossil fuels with non-conventional and renewable energy sources (wind, solar and biomass energy) are the main emission control measures.

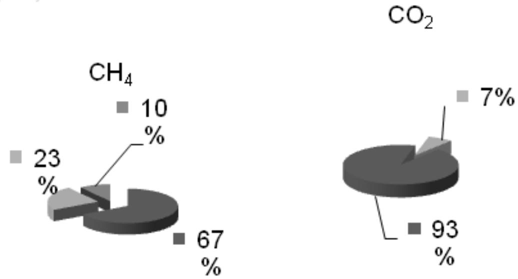

Fig. 1. Analysis of anthropogenic sources of greenhouse gases in Ukraine

Energy - 67 %
Agriculture - 23 %
Waste - 10 %

Natural fuel combustion - 93 %
Industrial processes - 7 %

The difference between biomass and other types of renewable energy when replacing fossil fuels is the following. The burning of biomass emits a corresponding amount of greenhouse gases, but as it grows, a similar amount of CO_2 is absorbed and thus there is no increase in the concentration of greenhouse gases in the atmosphere.

In addition, the use of wood as fuel reduces the emission of carbon oxides and sulphur into the atmosphere by up to 10% of the total amount of oxides generated by burning the widely consumed oil with high sulphur content in the world [1, 2].

Nevertheless, one of the main requirements for biomass energy technologies is to meet all environmental regulations and, first of all, to reduce as much as possible the emission of carcinogenic substances originating from biomass combustion [7-12].

The term biomass (BM) usually refers to carbon-containing organic substances of plant and animal origin (wood, straw, manure, etc.). Often the organic fraction of the organic fraction of municipal solid waste is also included in the term biomass.

Municipal solid waste. As a raw material for energy production biomass takes the first place among all kinds of renewable energy sources (RES) used nowadays [1,2,13,14], which is equivalent to 1250 mln. tce and makes about 15 % of primary energy sources in the world (in developing countries - to 38 %) [1,2]. It also plays significant role in industrialized countries - on the average 23 % of the total energy consumption (TEC): in the USA its share is 3,2 % [1,2], in Denmark - 6 % [2], in Canada - 7 % [1, 2], in Austria - 13 % [2], in Sweden - 16 % [1], in Finland - 20 % (maximum share for developed countries) [1, 2]; BM advantages as a fuel Complete absence or insignificant emission of sulphur compounds and preservation of equilibrium of carbon dioxide CO_2 in atmosphere. " The most widely used at present is vegetable BM.

The forecast of the World Energy Council (WEC) concerning the contribution of biomass in the energy sector of the future along with other renewable energy sources (RES) is shown in Figure 2 [17]. The term "modern biomass" means usage of modern industrial technologies of generation; energy production from biomass (domestic use of biomass for heat production and cooking is excluded). According to the prognosis the share of BM will make 42-46% of total share of RES in 2020, significantly exceeding contribution of solar, wind, geothermal and other types of RES.

Now in many countries there are plantations of fast-growing trees and high-yielding crops for energy needs (cultivation of rape for motor fuel in Germany, plantations of fast-growing wood species in Sweden, cultivation of sugar-cane for ethanol production in Brazil, etc.) [1, 2]. [1, 2].

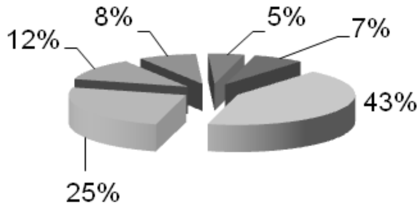

Fig. 2. Shares of non-conventional RES in the world (WECI forecast)

Biomass	-43%	Geothermal energy - 8%
Solar energy	-25%	Ocean energy - 5%
Wind energy	-12%	Micro hydropower - 7%

The main disadvantage of using biomass for energy purposes is that the energy produced by the technologies considered has a high cost and in most cases cannot compete with fossil fuels in the free market. Abroad these issues are addressed by subsidies for construction of energy facilities using biomass, as well as introduction of "green" taxes, i.e. development of this energy sector is based in Western countries on state support.

The scientific novelty of this work is the mathematical model proposed by the authors and substantiated by the authors for the efficient use of energy from different types of biomass in the global energy economy.

To study the possibility of extended use of biomass energy, a mathematical model was developed, the main elements of which are the information-energy network of the fuel and bioenergy balance (Fig. 3) and the database of bioenergy equipment.

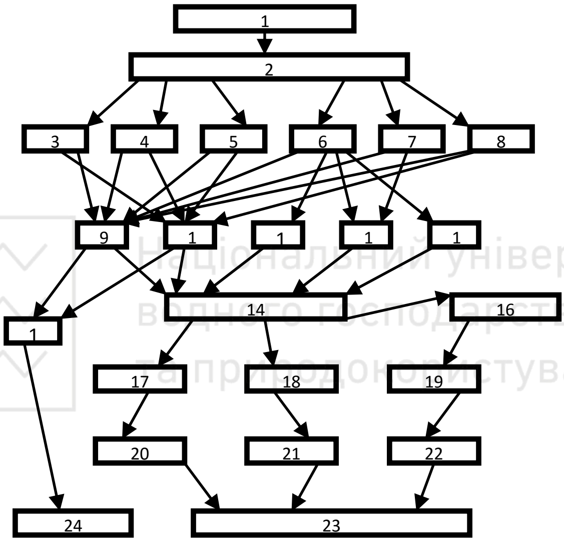

Fig. 3. Bioenergy balance information network Legend: *1* - biomass; *2* - transport and preparation; *3* - biomass of poultry complexes; *4* - biomass of pig complexes; *5* - biomass of cattle complexes; *6* - biomass of plant origin; *7* - organic part of municipal solid waste; *8* - municipal sewage; *9* - bioreactor-methanol; *10* - biofilter; *11* - pyrolysis; *12* - direct combustion; *13* - biomass gasification; *14* - biogas; *15* - micro-organic fertilizer; *16* - gas holder; *17* - biogas heat generator; *18* - electricity generator; *19* - autonomous biogas boiler; *20* - heat energy; *21* - electricity; *22* - heat energy; *23* - heat and electricity consumers; *24* - crop production

The generated information-energy network of fuel-bio-energy balance represents energy economy in the form of a set of objects of various types, exchanging energy flows. In the given scheme objects 3,4,5,6,7,8 are suppliers of commodity biomass to the world energy economy, and objects 23,24 are consumers of heat and electric energy as well as of microorganic fertilizers. The starting information for the study is data characterizing the energy balance by energy flow stages (extraction, processing, conversion, transport, storage, and end use).

The stages of the energy flow are represented in the nodes of the network. The lines connecting the nodes correspond to the energy flows between the respective nodes. Each type of node in the energy balance information network corresponds to its own computational unit in the form of a system of non-linear equations.

Several types of nodes are used in the energy information network, as shown in (Fig. 3): energy resource, transformation, reserve, decision, demand, nodes with many outputs and nodes with many inputs.

If we talk about Ukraine, a number of laws and programs (the Law of Ukraine N555-IY of 20.03.03) were adopted for the state support of activities and technologies based on biomass energy use. "On Alternative Sources of Energy", the Presidential Edict N1094/2003 "On Steps to Develop Bioenergy Fuel Production", National Energy Program of Ukraine till 2010, the Program of state support for the development of alternative and renewable energy sources and small hydro and heat energy technologies, etc.). However, the legal framework does not solve the overall problem due to the lack of funding sources, i.e. the search for processes and technologies with low capital and operational costs and low prime cost of the energy products obtained is relevant for Ukraine.

The main difficulties in the use of waste biomass as fuel in the existing energy units arise because of the different granulometric and chemical composition of biomass. The low bulk density makes the transport of biomass waste from the place of production to the consumer unprofitable, and the high volatile yield makes it difficult to combust biomass in the furnaces of existing energy units.

Thus, in Ukraine, the energy use of biomass is most promising for industrial enterprises (oil extraction plants, furniture factories, etc.) that produce significant amounts of biomass waste as a result of their main production. In this case, the economic effect of energy use is mainly determined by the capital costs of the equipment. In this case, the reconstruction of existing energy and energy processing equipment, allowing the use of biomass as fuel, is undoubtedly a more efficient direction compared to the installation of a new unit. This is especially true if the possibility of using fossil fuels as a reserve fuel remains [1,2].

Additional economic benefit from the energy use of biomass can be obtained by developing integrated technologies that give the possibility to obtain, in addition to the production of energy products, a product that is liquid on the market, e.g. carbon material, organic fertilizers, etc.

Analysis of biomass energy potential in Ukraine (Fig. 4) [1,14-16], conducted by the Institute of Technical Thermophysics of National Academy of Sciences of Ukraine and Scientific and Technical Centre "Biomass", showed that the share of industrial biomass waste is about 30% of the total biomass potential.

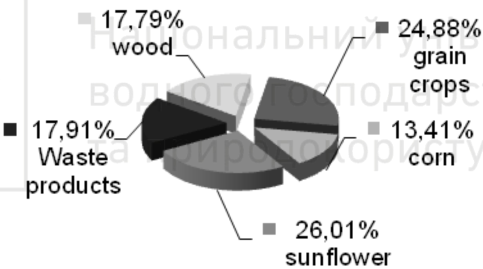

Fig. 4. Energy potential of biomass in Ukraine

Currently, biomass in Ukraine covers about 0,5% of its primary energy needs (~1 million tce) [3].

Presence of biomass fuel potential in Ukraine requires analysis of the existing technologies of its energy use, first of all, from the ecological point of view, including determination of the specific emission of greenhouse gases. The latter is especially topical in the implementation of projects under the Kyoto Protocol.

The choice of technology is determined by properties of different types of biomass as energy fuel. The calorific value of most types of biomass waste is within the range of 13-19 MJ/kg [1,14-16,20]. The main influence on the calorific value is the moisture content of the fuel [18,19].

The presence in biofuels of impurities such as chlorine (in wood - 0,1 %, in straw - up to 0,75 %) [1, 18, 19] reduces its quality which is compensated by a low sulphur content (0,2-0,77 %) [1], compared to domestic coal (*Sp*=2-3 %).

The ash content in biomass depends on time of year, soil, climate, etc. The real ash content of wood fuel including storage and transport reaches 1,5-2 % due to wood contamination. The ash content of biomass in the form of straw from different crops, sunflower husks, rushes, needles, etc. exceeds that of wood and is mostly in the range of 3-7 % [1,2], and ash content of rice hulls can reach 20 % of the fuel working mass.

The shape and size of the particles which make up the biomass waste have a great influence on the way they are used. The dispersion composition of the particles is also important. In the case of organic waste, we are usually dealing with materials consisting of finely dispersed particles of different shapes and with low bulk density (120-260 kg/m^3) [1,3,20]. Chemical composition of biomass waste causes high volatile matter yield when heated (70-75 %). These features of biomass waste have to be considered when choosing and improving technologies and equipment for their use for energy purposes.

Theoretically, depending on the moisture content, biomass is processed by thermochemical or biological methods. Biomass with low moisture content (agricultural and municipal solid waste) is processed using thermochemical processes: direct combustion, gasification, pyrolysis, liquefaction, hydrolysis. Biomass with high moisture content (sewage, municipal waste) is recycled using biological processes.

In practice, the following methods of processing biomass for energy production are used:

- direct combustion for direct production of heat;
- gasification of biomass;
- pyrolysis (dry distillation), aimed at obtaining the maximum gaseous fuel (mainly hydrogen and CO). The producer gas has a calorific value of 4-8 MJ/m^3;
- alcohol fermentation to produce ethyl alcohol (ethanol) from biomass
- alcohol (ethanol);

- anaerobic digestion, which is the most promising
- means of obtaining fuel from organic matter.

Estimated calculations made in (Fig. 4) show that in Ukraine a large amount of biogas can be obtained annually from the manure if it is fully processed by bioconversion.

When assessing the economic efficiency, it should be taken into account that the biogas plant provides simultaneous decontamination of manure and fertilizer production. It is also part of a system of environmental protection measures. In this case, biogas plants will always have a positive effect on the economy.

Biogas is also produced from municipal (cities and urban-type settlements) wastewater. Its output is 0,001 m^3 per 1m^3 of waste water.

The following anaerobic methane digestion regimes are known: psychophilic (digestion temperature °C), mesophilic (°C) and thermophilic (°C).

METHODOLOGY FOR DETERMINING THE ENVIRONMENTAL EFFICIENCY OF BIOENERGY FUEL USE

1. Environmental criteria for assessing the energy use of biogas

One of the main goals of biogas energy use, as mentioned above, is to reduce greenhouse gas emissions when replacing fossil fuels. This implies determining emissions before and after biogas use. The determination of emissions is based on a systematic approach, when the calculation is made taking into account emissions from fuel extraction, transportation, fuel consumption for equipment manufacturing, etc. At the same time, the life cycle of equipment and capital facilities is considered [72,147,183].

As a rule, these methods allow determining emissions in relation to specific technologies and equipment, as well as fuel types. As a result, the following are determined:

- is the absolute value of emissions for the considered period of time $K_{CO_2}\left[gCO_2-\frac{eq}{hour}\right]$,
- emission rate (given emission) referred to a unit of feedstock - $k_{\mathrm{CO}_2}\left[q\mathrm{CO}_2-\frac{eq}{J}\right]$ or $e_{\mathrm{CO}_2}\left[q\mathrm{CO}_2-\frac{eq}{m^3}\right]$.

❖ specific emission E_y per unit of useful energy $\left(q CO_2 - \frac{eq}{hour}, q CO_2 - \frac{eq}{Gcal}\right)$.

These indicators allow us to estimate the reduction of emissions from the production of the same type of energy. However, comparing these indicators in the production of different types of energy is not objective. In addition, the obtained indicators are not direct characteristics, but are indirect. Thus, the adopted emission reduction indicators do not allow for an objective comparison of different technologies and equipment, the efficiency of using different types of biofuels and assessing the impact of their quality on the final result, as well as fully taking into account the impact of the type and quality of the substitute fuel.

At the same time, the amount of biogas that can be used for energy purposes is limited. For example, according to estimates of [7, 130], the amount of biogas that can be used for energy purposes is 9,07 million tons of equivalent fuel per year, which does not exceed 4,6% of primary energy consumption in the country. This potential should be utilized with maximum efficiency.

In this regard, the development of performance indicators for the ecological use of biofuels is becoming relevant from this point of view.

The above-mentioned developments are computer programs with corresponding databases. One of the peculiarities of using these programs, in our opinion, is that, on the one hand, they allow for a specific calculation with maximum detail and assessment of the "integral" result. At the same time, the analysis of the interaction of various factors remains hidden, which can often lead to erroneous conclusions. This is especially true for generalizing (strategic) analysis. Therefore, computational studies should be supplemented by analytical studies that allow us to identify the main relationships between parameters.

This is the approach we used to develop the indicator of specific greenhouse gas emission reduction when replacing fossil fuels with biogas - k_{CO_2} [147].

$$k_{CO_2} = \frac{K^{N.F.} - K^{BG}}{B_{BG} * Q_{NF}^{R}}$$

where $k^{N,F}$,k^{BG} is the absolute value of greenhouse gas emissions when operating on natural fuel and biogas, respectively, kg $q\mathrm{CO}_2 - \frac{eq}{hour}$;

B_{EG} - biogas consumption, m^3/hour;

Q^R_{NF} - is the calorific value of biogas, J/m^3.

The determination of greenhouse gas emissions is based on the use of the emission factor [kg CO_2 eq/kg], which is an unambiguous characteristic of a given fuel type. Then the absolute value of emissions can be calculated according to the following equation

$$K = B \cdot e_{\mathrm{CO}_2}, \qquad (2)$$

where B - is fuel consumption, m/hour^3

In turn, fuel consumption is determined by the performance of the power unit and its efficiency - η_Σ

$$B = \frac{Q_u}{Q^R_N \cdot \eta_\Sigma},$$

Assuming that useful energy Q_u production is the same before and after the replacement of natural fuels and taking into account expressions (4.2) and (4.3), the form of the dependence for determining the specific reduction of greenhouse gas emissions - $\varepsilon_{\mathrm{CO}_2}$ (1) will be transformed into an expression that does not contain useful energy

$$k_{CO_2} = k^{N.F.} * \frac{\eta^{BG}_\Sigma}{\eta^{N.F}_\Sigma} - k^{BG},$$

where, $k^{N.F.} = \frac{e^{N.F.}_{CO_2}}{Q^R_{N,NF}}$; $\quad k^{BG} = \frac{e^{BG}_{CO_2}}{Q^R_{N,BG}}$.

Thus, the main parameters that affect the efficiency of biogas use to reduce greenhouse gas emissions when replacing fossil fuels are:

- greenhouse gas emission rates per unit of calorific value of fuel, $k^{N,F}$, $k^{B,G}$ similar to [2-6];

- the ratio of the efficiency of energy units before and after the replacement of natural fuel, whereby the gross efficiency is the total efficiency of energy consumption for own needs and losses (including biogas pretreatment).

In the case of co-combustion of biogas and natural fuel, with its partial replacement, the dependence for calculation will be transformed to the form

$$k_{CO2} = \left(k^{N.F.} \cdot \frac{\eta_{\Sigma}^{M}}{\eta_{\Sigma}^{N.F.}} - k^{M} \right) \cdot \frac{1}{(1-a')},$$

where $$k^{M} = \frac{e_{CO_2}^{M}}{Q_{N,M}^{R}} = \frac{e_{CO_2}^{N.F..} \cdot a + e_{CO_2}^{BG}(1-a)}{Q_{N,N..F}^{R} \cdot a + Q_{N.BG}^{R}(1-a)},$$

a - mass fraction of natural fuel in the mixture;

a' - the energy share of natural fuel in the mixture is equal to

$$a' = \frac{Q_{N,NF}^{R}}{Q_{N,M}^{R}}$$

As is well known, the value of efficiency is determined by the technical level of the equipment and energy conversion technology used, both when burning natural fuels and biogas. In addition, the value of efficiency is also related to the efficiency of equipment use over time, which is especially important in the case of co-generation of heat and electricity.

A special place is occupied by the case of partial utilization of the energy potential of biogas, for example, when using anaerobic fermentation technology. In this case, the shaved residue can be used as a material for technological needs (production of high-tech fertilizers). Accordingly, in expression (4), the efficiency of a power unit operating on biogas should take into account the heat losses during anaerobic fermentation, and the calculation of the emission factor should be made in relation to the combustion of volatile products of this process.

A systematic approach to determining the value of the emission indicator, similar to [183], includes summing up greenhouse gas emissions along the entire technological chain of fuel use, from extraction to combustion. Thus, the structure of the emission indicator for any type of fuel consists of four main components: emissions from fuel extraction - k^{prod}, its transportation - k^{tr}, processing - k^{proc}, fuel combustion - k^{com}. Then the general type of dependence for calculating the emission factor can be represented as the sum of

$$k = k^{prod} + k^{tr} + k^{proc} + k^{com}, \tag{8}$$

Graphically, this dependence for natural fuels is shown in the diagrams (Fig. 1,2). Thus, the value of the emission indicator depends on the national characteristics of the energy complex of each country (availability of own fuel resources, structure and characteristics of the energy and mining industries, territorial location, etc.) Below are the methods for determining the emission factor for the main types of fossil fuels and biogas in relation to the conditions of Ukraine.

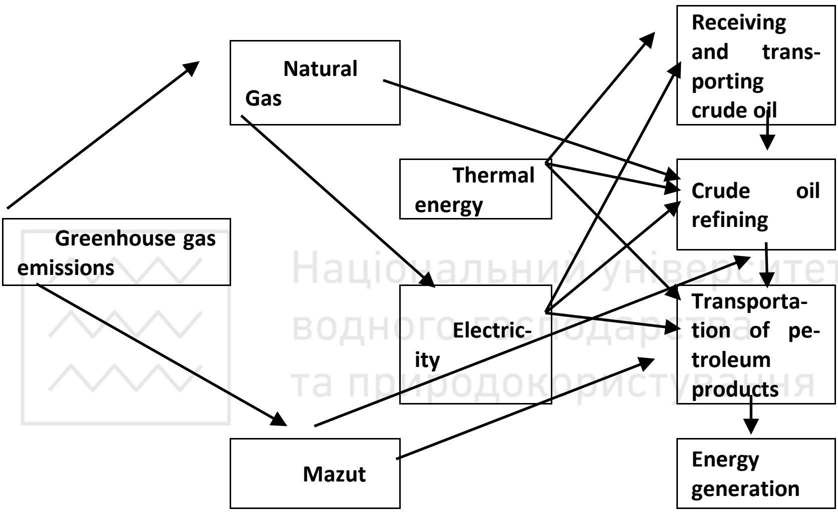

Fig. 1. Scheme of calculation of greenhouse gas emissions from natural gas combustion

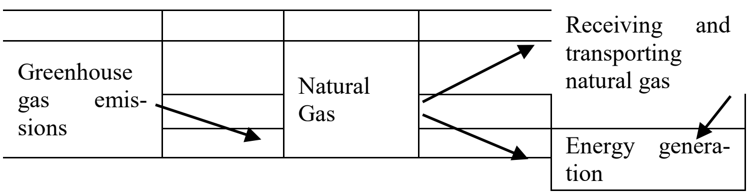

Fig. 2. Scheme for calculating greenhouse gas emissions from fuel oil combustion

2. Methodology for calculating emission indicators for biogas production by anaerobic digestion of biomass

The greenhouse gas emissions from anaerobic digestion of biomass for energy are related to emissions from the combustion of fossil fuels at the stage of collection, processing and. Given that biomass suitable for energy use in Ukraine is treated as a waste product, greenhouse gas emissions associated with harvesting and collection of biomass were not taken into account, as energy consumption was fully attributed to the production of the main product. In this case, the emissions figure for biogas k_{CO_2} consists of two components

$$k^{BG}_{CO2} = k^{BM}_{ferm} + k^{BM}_{proc}, \qquad (9)$$

where k^{BM}_{ferm} - $g[CO]_{\downarrow}2-eq/kg$ of biogas equivalent).

k^{BM}_{proc} - greenhouse gas emissions are related to the fermentation process (unloading and loading of biomass, as well as mixing costs), $g[CO]_{\downarrow}2-eq/kg$ of biogas equivalent).

Biofuel production processes using anaerobic fermentation include electricity costs for unloading, loading, and mixing biomass, as well as heat for substrate preparation and thermal stabilization of reactors. Electricity consumption for these types of processes is summarized in Table 1 [184].

Table 1

Specific electricity consumption in anaerobic biomass fermentation [184]

Type of equipment used	Pumps for loading and unloading	Stirrers in the reactor	Other process equipment
Electricity consumption (for a Danish reactor with a volume of 800 m^{3}of biomass) b^{BM}_{ee}, kWh/t	5-12	5-7	3-5
Electricity costs (for small farms) installations of 130-150 m^{3}of biomass) b^{BM}_{ee}, kWh/t	2-4	1-3	0,5-2

Accordingly, the greenhouse gas emissions associated with biomass chipping and anaerobic digestion of biomass were determined by the following dependencies

$$k_{CO_2}^{BG} = b_{ee}^{procBM} * E_{ee} + b_{ee}^{fermBM} * E_{ee}$$

The processes of preparing biomass as an energy fuel include two alternative processes: shredding and pressing (briquetting). The energy consumption for shredding depends on the finite size of biomass particles and the type of biomass in Table 2 [184].

Table 2

Specific electricity consumption during biomass grinding [184]

Particle size, mm	>25	>15	>10	>5	>3
Specific energy consumption $b_{ee}^{chip\ BM}$, kWh/t	10-25	20-5	25-45	40-80	60-130

Accordingly, the greenhouse gas emissions associated with biomass chipping were determined by the following dependence

$$k^{chipBM} = b_{ee}^{chipBM} * E_{ee} \qquad (11)$$

In the case of further pressing and pelletizing, biomass can be pressed and pelleted using several well-known processes, the name of which determines the type of equipment used [150,152]. Electricity consumption directly for biomass pressing is 20-70 kWh/t (Table 3) [12,154].

Table 3

Energy consumption during briquetting and pelletizing of biomass

Type of used equipment	Rolling press	Screw press
Electricity consumption $b_{ee}^{pres\ BM}$, kWh/t	20-60	50-70

Accordingly, the greenhouse gas emissions from biomass pressing include emissions associated with the use of electricity

$$k^{pres\ BM} = b_{ee}^{presBM} * E_{ee}, \qquad (12)$$

Then the total greenhouse gas emissions for biomass preparation and processing are equal to

$$k_{proc}^{BM} = k^{presBM} + k^{chipBM}, \qquad (13)$$

The above methodology made it possible to estimate greenhouse gas emissions for different types of natural fuels and biomass, on the basis of which various options for biomass energy technologies and equipment were compared.

3 Determination of the emission factor for natural gas use

Due to the fact that the share of imported natural gas used in Ukraine exceeds 80% of the gas consumed in 2007-2019 [150, 183], the calculation of the emission indicator took into account energy consumption only for gas transportation and its use in power units.

Ukraine has a developed gas transportation system with a length of 36,7 thousand km, which includes 72 compressor stations [161]. The system's inlet capacity is 290 billion m^3 per year. The gas transportation system provides gas supply to domestic consumers and transit of Russian natural gas to European countries. Over the past 10 years, the volume of natural gas transit has amounted to 113-137 billion m^3 per year. Intensive operation of the gas transportation system has led to the need to reconstruct and replace pipelines and compressor equipment. More than a third of gas pipelines have been in operation for 23 to 48 years. A significant number of gas pumping units have low technical performance (efficiency), resulting in gas transportation costs of 5%-6% of the transported gas [161, 183]. Thus, the specific consumption of natural gas for its transportation is b_{TR}^{NG} =0,05-0,06 kg per t/kg per p. The greenhouse gas emissions during the transportation of natural gas k_{TR}^{NG} were determined based on the conditions of fuel combustion in gas pumping units

$$k_{TR}^{NG} = b_{TR}^{NG} * k_{cf}^{NG}, \qquad (14)$$

where k_{cf}^{NG} - indicator of emission during combustion of natural gas which is calculated according to dependence (4.15), $g[CO]_{\downarrow}2-eq/kg$ of fuel equivalent).

In this case, fuel combustion means either direct combustion in different types of furnaces or after thermal processing (anaerobic fermentation, pyrolysis, gasification) with subsequent combustion of the processing products in power units: boilers, engines, gas turbines.

Using the values of specific emission, $э_{CO_2}, э_{N_2O}, э_{CH_4}$, the greenhouse gas emissions from fuel combustion k^{cf} were calculated according to the following dependence

$$k^{cf} = э_{CO_2} + GWP_{CH_4} э_{CH_4} + GWP_{N_2O} э_{N_2O}, \qquad (15)$$

where GWP_{N2O} -is the conversion factor of N_2O to CO_2 - equivalent, equal to 310 [10];

GWP_{CH4} - is the conversion factor of methane to CO_2 - equivalent (Global Warming Potential), equal to 21 [10];

$э_{CH4}, э_{H2O}$ - Specific emissions of nitrous oxide and methane from fuel combustion in in the process units gCN_4 /kg of fuel oil and gN_2O/kg of fuel oil, respectively.

In case of direct combustion of fuel in boiler furnaces, the data in Table 4.4 can be used to determine the specific emissions.

Table 4

Values of specific emissions of CO_2, N_2O and CH_4 from fuel combustion in Ukraine emissions from fuel combustion in Ukraine

Type of fuel	Fuel oil	Natural gas
$э_{CO2}$, CO_2 г/ кг у.п	2281-2353	1527-1669
$э^{ээ}_{CH4}$, CH_4 г/ кг у.п	0,237-0,0281	0,143-085
$э^{ээ}_{N2O}$, N_2O г/ кг у.п	0,261-0,083	0,227-0,084

The total greenhouse gas emissions for natural gas use are as follows

$$k^{NG} = k^{NG}_{cf} + k^{NG}_{TR} \qquad (16)$$

4. Determination of the emission factor for biogas use

The study of environmental efficiency of energy technologies requires knowledge of emission indicators for both main types of fossil fuels and bioenergy fuels. Due to the lack of necessary data in the national literature on the conditions of Ukraine, the study developed atic approach

Analyzing the dependence of the specific reduction in greenhouse gas emissions

$$\varepsilon_{CO_2} = k^{N.F.}\left(\frac{\eta_{\Sigma}^{\text{BioG}}}{\eta_{\Sigma}^{\text{N.F.}}} - \frac{k^{BioG}}{k^{N.F.}}\right), \qquad (17)$$

where $k^{N.F} = \dfrac{Э^{N.F}}{Q^{R}_{N.N.F}}$; $k^{N.F} = \dfrac{Э^{N.F}}{Q^{R}_{N.N.F}}$; $k^{BioG} = \dfrac{Э^{BioG}}{Q^{R}_{N.BioG}}$

which shows that it is determined by three quantities: the ratio of emission rates and efficiency of energy units, as well as the absolute value of fossil fuel emissions.

Using the developed methodology, quantitative data on the change in greenhouse gas emissions k_{CO2} for the conditions of Ukraine have been determined, which amounted to:

when burning gasoline - 2188÷2329), $g[CO]_{\downarrow}2-eq/kg$ of fuel oil);

when burning fuel oil - 2414÷2552), $g[CO]_{\downarrow}2-eq/kg$ of fuel oil equivalent);

for natural gas combustion - 1712÷1910), $g[CO]_{\downarrow}2-eq/kg$ of fuel equivalent);

for biogas combustion, anaerobic digestion of biomass - 1037÷1253), $g[CO]_{\downarrow}2-eq/kg$ of fuel equivalent).

Based on the calculated data on greenhouse gas emissions for the main types of fossil fuels in Ukraine (Table 5), and comparing the value of biogas combustion emissions $k^{BioG}_{CO_2}/k^{grh}_{CO_2}$ the ratio varies in the range of 0,29-0,65. For each type of natural fuel, the value of this ratio is given in Table 6 and in [148].

Table 5

Greenhouse gas emissions for the main types of fossil fuels in Ukraine

Type of fuel	Petrol		Fuel oil		Natural gas	
	g[CO] of fuel oil)	%	g[CO] of fuel oil)		g[CO] of fuel oil)	%
m_{max}	k^{prod}	1,88	0,1	1,87	0,1	-
	k^{tr}	2,03	0,1	2,95	0,1	93,4
	k^{proc}	147,3	6,5	147,3	5,6	-
	$k^{трнп}$	65,3	2,7	19,0	0,7	-
	k^{com}	2113	90,6	2381	93,2	1817
	k	2329	100	2552	100	1910
m_{min}	k^{prod}	1,39	0,1	1,4	0,1	-
	k^{tr}	0,1	0,0	0,1	0,0	72,8
	k^{proc}	75,1	3,5	75,4	3,4	-
	$k^{трнп}$	1,2	0,0	-	-	-

	k^{com}	2111	96,4	2338	97,3	1639
	k	2188	100	2414	100	1712

Given that the ratio of efficiency coefficients in dependence (17) does not differ much from one, it can be argued that the amount of greenhouse gas emissions from biomass can change the final result by 3-7%.

Table 6

Values of the ratio of biogas emissions from anaerobic digestion and natural fuels, $k^{BioG}/k^{N,F}$

Type of replacement fuel	coal	petrol	fuel oil	diesel fuel	natural gas
Maximum value	0,3	0,54	0,49	0,47	0,65
Minimum value	0,29	0,47	0,41	0,42	0,6

Using the obtained values of emission indicators (Table 5 and Table 6) for natural gas and biogas obtained from anaerobic digestion of biomass, the values of specific greenhouse gas emissions in the production of thermal Pk_{tem} and electric energy Pk_{ee} in Ukraine were determined according to the following dependencies

$$Pk_{ee} = k * b_{ee};\ Pk_{tem} = k * b_{tem}, \tag{18}$$

The values of specific fuel consumption for heat production were based on the passport indicators of boiler equipment offered on the Ukrainian market, as well as data from prototypes of boiler units converted to bioenergy fuel (Table 4.7), and the values of specific emissions are also given there.

Table 7

Characteristics of hot water boilers

Heat output	Type of fuel	Efficiency	Specific fuel consumption, kg of fuel equivalent/Gcal	Specific greenhouse gas emissions, $Pk_{\tau ev}$, $kgCO_2$ -eq/Gcal
Up to 10 kW	natural gas	84-2	169-152	322,1-260,4
Up to 10 kW	biogas	70-88	177-159	232,8-194,3
Up to 100 kW	coal	77-84	185-170	804,7-571,9
Up to 100 kW	natural gas	84-92	170-155	324,4-265,7

Based on the efficiency values of hot water boilers fired by fossil fuels and biogas produced by anaerobic digestion, the values of specific greenhouse gas emissions from heat Pk_{tem} production in Ukraine were determined. Based on the efficiency values of hot water boilers with a capacity of up to 10 kW, operating on natural gas and biogas obtained from anaerobic digestion (Table 4.7), it is necessary to assume that the ratio $\eta_{\Sigma}^{BioG} / \eta_{\Sigma}^{N.G}$ can vary from 0,833 to 0,956.

The data shows that the efficiency of power units significantly affects the result of replacing fossil fuels with biogas produced by anaerobic digestion.

It is interesting to analyze the co-combustion of natural gas and biogas produced by anaerobic digestion. With partial replacement of natural gas with biogas produced from anaerobic digestion, the emission rate for the fuel mixture decreases in proportion to the share of biogas (Fig. 4.3).

When modeling the operation of boilers with a capacity of up to 10 kW with partial replacement of natural gas with biogas produced by anaerobic digestion, these factors were taken into account. The results of the calculations showed that the change in boiler efficiency is not significant up to 3% (Table 8). The actual experience of co-combustion of natural gas with biogas produced from anaerobic digestion confirms the results of a slight change in boiler efficiency [142, 144].

Table 8

Performance of boilers with partial replacement of natural gas with biogas obtained from anaerobic digestion of biomass

The mass share of natural gas in mixtures with biogas	0,6	0,8	1
Boiler efficiency, %	85,2	85,6	87,9
$\eta_{\Sigma}^{CM} / \eta_{\Sigma}^{N.G}$	0,969	0,974	1
k_{CO2} max, $q[CO]_{\downarrow} 2 - eq / kg$ of fuel oil),	1646,0	1777,0	–
k_{CO2} min, of $q[CO]_{\downarrow} 2 - eq / kg$ fuel oil),	1443,2	1578,6	–

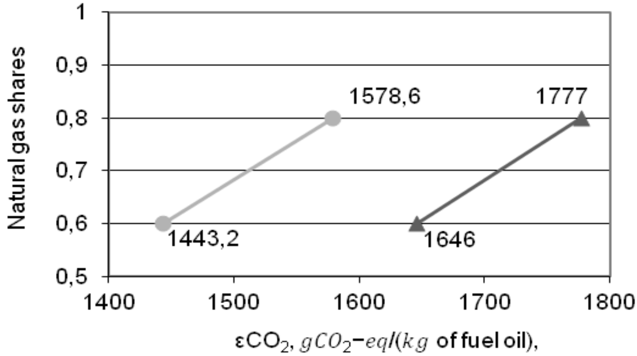

Fig. 3. The value of the emission factor ε_{CO2} depending on the energy share of natural gas when co-combusted with biogas

All of the above demonstrates the relevance of the development of bioenergy fuel combustion technology obtained from anaerobic digestion of biomass and further research in this area.

5. Conclusions

1. A methodology has been developed that allows analysing the environmental efficiency of energy use of biogas obtained from anaerobic digestion of biomass based on the specific reduction k_{CO2}. This indicator makes it possible to objectively compare existing and proposed technologies and equipment for the use of bioenergy fuels, while fully taking into account the complex impact of the type and quality of the substitute fuel on the emissions and efficiency of thermal units.

2. Using the developed methodology, quantitative data on the change in greenhouse gas emissions k_{CO_2} for the conditions of Ukraine were determined, which amounted to:

- for gasoline - 2188÷2329 g_{CO_2} - eq/kg of fuel oil),
- fuel oil - 2414÷552 g_{CO_2} - eq/kg of fuel oil equivalent,
- natural gas - 1712÷1910 g_{CO_2} - eq/kg fuel oil equivalent,
- combustion of biogas produced by anaerobic digestion of biomass - 1037÷1253 g_{CO_2} - eq/kg fuel oil equivalent.

3. On the basis of the performed studies, the ranges of possible specific reduction of greenhouse gas emissions when replacing natural gas with bioenergy fuel obtained from anaerobic digestion of biomass were determined. The value can vary when replacing (60% of natural gas and 40% of biogas) in the range of 1443,8÷1646,0 g_{CO_2} - eq/kg of fuel oil equivalent, and when replacing (80% of natural gas and 20% of biogas) in the range of 1578,6÷1777,0 g_{CO_2} - eq/kg of fuel oil equivalent equivalent.

2. Development of a methodology for determining the value of greenhouse gas emission indicator of greenhouse gases under conditions of Ukraine

A systematic approach to determining the value of the emission indicator, similar to [13-16,68], includes the summation of greenhouse gas emissions throughout the technological chain of fuel use, beginning with the extraction and ending with its combustion. Thus, the structure of the emission indicator for any fuel consists of four main components: emission during fuel production - $e_{CO_2}^{prod}$, its transport - $e_{CO_2}^{transp}$, recycling - $e_{CO_2}^{proc}$, fuel combustion - $e_{CO_2}^{comb}$. The general form of the relationship for calculating the emission factor can then be represented as the sum of

$$e_{CO_2} = e_{CO_2}^{prod} + e_{CO_2}^{trasp} + e_{CO_2}^{proc} + e_{CO_2}^{comb} \tag{2.7}$$

In this calculation, all the main energy carriers (fuels, heat and electricity) used in all the technological steps are taken into account.

Graphically this dependence for different fossil fuels is shown in figures 2.1, 2.2, 2.3.

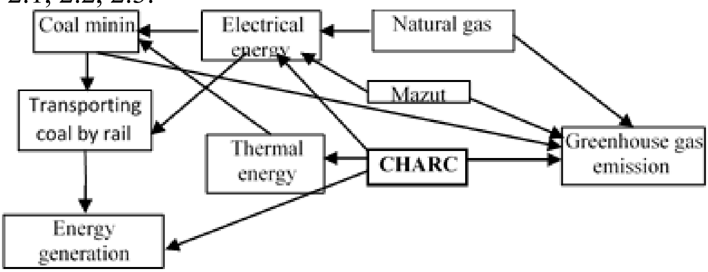

Figure 2.1. Schematic diagram for calculating the greenhouse gas emission index

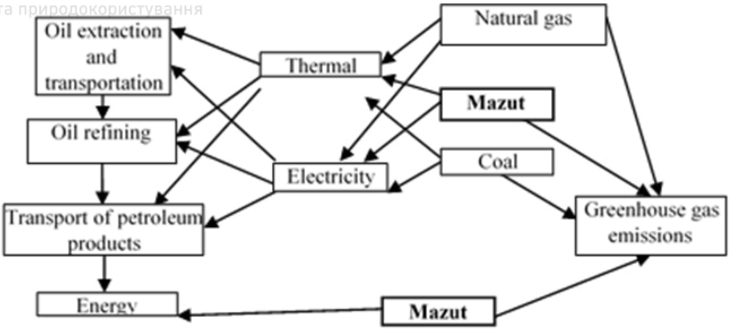

Figure 2.2. Calculation scheme of the greenhouse gas emission index

emissions from fuel oil combustion

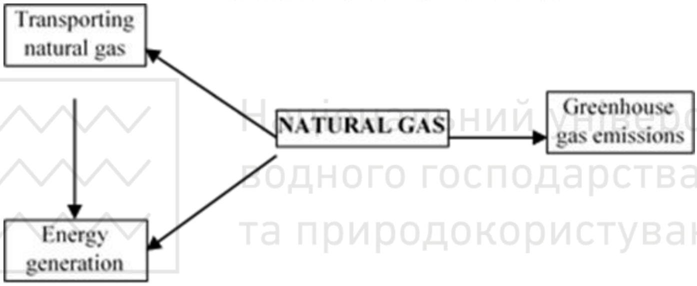

Fig.2.3 Calculation scheme for reduced greenhouse gas emissions emissions from natural gas combustion

Thus, the value of the emission indicator depends on the national characteristics of the energy complex of each state (availability of own fuel resources, structure and characteristics of the energy and extractive industries, territorial location, etc.). Below the methodologies for determining the emission index for the main types of fossil fuels and biomass in relation to the conditions of Ukraine are given.

2.2.1 Methodology for determining greenhouse gas emissions from coal combustion under Ukrainian conditions.

Coal production in Ukraine is carried out mainly by underground mining (about 99% [86]). In this regard, when developing the algorithm, we used the data on electricity and heat consumption typical for this method of mining, with regard to the conditions of the Donetsk coal basin, where more than 80% of domestic coal is mined. The main sources of greenhouse gas emissions from coal mining are electricity and heat consumption and methane emissions from mine ventilation and degassing. Accordingly, the reduced greenhouse gas emissions from coal mining $e_{CO_2}^{prod}$ have been determined using the relationship

$$e_{CO_2}^{prod} = b_{Tem}^{y} E_{Tem} + b_{ee}^{y} E_{ee} + э_{CH4}^{m} + GWP_{CH4} + э_{CO_2}^{m}, \qquad (2.8)$$

where is E_{Tem} specific greenhouse gas emission in thermal energy generation, kgCO$_2$-eq/Gcal;

E_{ee}- specific greenhouse gas emission in electricity generation, kgCO$_2$-eq/kWh;

$GWP_{CH\,4}$ - methane-to-CO$_2$-equivalent conversion factor (Global Warming Potential) equal to 21[87];

$э_{CH4}^{m}$ - mine methane emission factor, gCH$_4$/kg CO;

$э_{CO_2}^{m}$ - is the carbon dioxide emission rate from combustion of excess of coal mine methane, gCO$_2$/kg teq;

b_{Tem}^{y}, b_{ee}^{y} - specific heat and electricity consumption during coal extraction, kWh/kg fuel equivalent (Gcal/kg fuel equivalent).

The methodology for determining specific greenhouse gas emissions associated with the use of heat and electricity, and taking into account the structure of electricity production and fuel consumption, as well as losses during transportation, is given in Annex A.

The main electricity consumption in coal mining is related to mine ventilation, lifting, dewatering, underground transport port operation, compressed air production and lighting. Depending on the production technology and the mining conditions, the specific electricity consumption may vary by several times [88-92]. Additionally, the specific power consumption increases due to the high ash content of coal mined in Ukraine and consequently its low calorific value.

The real range of possible values of specific electricity consumption in coal mining is as follows: the minimum value of energy consumption typical for mines of the State Holding "Pavlogradugol" - b_{be}^{y} =22,1 kWh/t (0,04 kWh/kg t) [90], maximum value - for Production Association "Artemugol" - b_{be}^{y}=459 kWh/t (0,647 kWh/kg t) [91]. The average value of specific electricity consumption for the industry for the year 2000 b_{be}^{y} is =105,2 kW·h/t (0,1837 kW·h/kg t).

In contrast to electricity, which accounts for 20-50 % of the cost of coal, the consumption of thermal energy has attracted less attention from coal producers. This is primarily due to the fact that heat is produced in own boiler-houses from their own coal and thus the costs of this type of energy are much lower and up to now there is no standardised metering system in place. This significantly reduces the reliability of information on heat consumption during coal extraction.

At the same time it is known, that specific heat consumption by pre-mining of coal in the period of the planned economy was in 1985 - 1990 b^{y}_{Tem} =25-26 kcal/kg (or taking into account the quality of coal mined in Ukraine 38-39 kcal/kg fuel equivalent) [114]. These data can be taken as the lower bound of the energy input range. The upper limit, as in the case of power consumption, exceeds the lower limit by several orders of magnitude, and on data for 1997 at the Artemugol production association was b^{y}_{Tem} =220 kcal/kg (310,2 kcal/kg resistivity), and at Kirovskaya mine b^{y}_{Tem} -567 kcal/kg (799,0 kcal/kg resistivity).

Methane emissions from underground coal mining are associated with the need to ventilate and degasify coal seams to prevent explosions. Sources of methane are [84]:

- ventilation systems (methane concentration 0,2-1 %);
- vertical pre-degasification wells from the surface (methane concentration 80-90%);
- vertical wells from the surface at the waste sites (methane concentration 20-60%);
- horizontal and inclined underground degassing wells (methane concentration 20-60%).

In addition, methane emission does not stop even after the liquidation of mines [116]. For example, in the abandoned Tsentralnaya-Pervomayskaya mine, methane has been emitted for about 20 years. At the same time the efficiency of utilisation of mine methane is very low. According to different estimates [117 118] the share of utilized methane does not exceed 4-8 % of total emissions. The absolute quantity of methane emitted per year amounts to 2,1-2,428 bcm m^3, of which, according to [118], 80% is related to ventilation units, and around 20% - to de-gasification units. Part of the methane produced by the degassing units (200-207 million m^3/year) is used in boilers, and also for fueling vehicles, and the rest is combusted in flares. Thus, 80% of the mine methane from the ventilation units is emitted into the atmosphere, plus an additional 12% of the methane from the combustion in the candles. Considering the balance of coal mine methane and the quality of domestic coals the specific emission of coal mine methane is $э^{m}_{CH4}$ =34,9 gCH_4/kg t, and the specific emission of CO_2 from combustion of coal mine methane in a fuel candle is $э^{m}_{CH_2}$ =0,01 gCO_2/kg t.

The high ash content of coal mined in Ukraine implies enrichment before transportation, which requires additional energy costs.

The status quo [104] is that more than 50% of steam coals and more than 10% of anthracites go to power plants bypassing beneficiation plants. The rest of the coal is enriched. The enriched coal is mainly supplied to the metallurgical and municipal sectors. From enrichment plants the CHPPs get small fractions of the enriched coal with A^d=22 %, dry elimination of small fractions with ash content corresponding to the rank coal, intermediate products and slime with ash content A^d=39-45 % [104]. In this regard, the energy consumption for enrichment cannot be fully attributed to coal used in the energy sector, so it was not taken into account in the calculation of greenhouse gas emissions.

The lack of major rivers in the area of the Donetsk coal basin and the developed railway network in Ukraine (more than 22500 km [119]) have led to the fact that the main amount of coal is transported by rail. According to the Ministry of Transport, the share of transportation by electric traction exceeds 80% of the total turnover in Ukraine [120]. Therefore, when calculating greenhouse gas emissions during coal transportation, one hundred percent use of electric traction is assumed.

Electricity consumption and related greenhouse gas emissions are directly proportional to the distance of coal transportation S^{y}_{transp}[km]. The location of the Donetsk coal basin is such that the maximum distance of coal transportation within the borders of Ukraine does not exceed 1400 km [121], and the average specific power consumption taking into account the weight of the wagons (tare) according to [122] was 0,013-0,014 kWh/(t km gross) in 1995-1996. The characteristics of wagons used for coal transportation are given in Table 2.1 [123]. Thus, the weight of the transported coal is 25%-27% less than the weight of the railway stock. Correspondingly, specific power consumption increases by the same amount, compared to [122], and amounts to 0,0173-0,0187 kWh/tkm. Similar data given in [123] exceed the mentioned specific consumption twice, making 0,035-0,04 kWh/t km, and practically equal to the value of electricity consumption during coal transportation in Germany in 1990 - 0,03 kWh/(t km) [112].

Therefore, the unit electric energy consumption for coal transportation is 0,02-0,04 kWh/t km, or taking into account the averaged coal quality parameters in Ukraine b^{y}_{transp}=3,47·10-5 - 6,95·10-5, kWh/(kg tce(coal)·km). The greenhouse gas emissions from transport are then

$$e^{transp}_{CO_2} = S^{y}_{transp} * b^{y}_{transp} * E_{ee}, \qquad (2.9)$$

where b^{y}_{transp} - specific electricity consumption for coal transportation by rail, kWh/kg of fuel equivalent (coal)·km;

S^{y}_{transp} - transportation distance, km.

Table 2.1

Technical characteristics of wagons, used for coal transportation in CIS countries

Name	Indicator values			
Load capacity, *t*	62	63	93	125
Number of axles, *pcs*.	4	4	6	8
Tare, *t*	22,7	21,8	31,5	43,3
Gross wagon weight, *t*	84,7	84,8	124,5	168,3
Net/gross weight ratio, *t/t*	0,73	0,74	0,75	0,74

The greenhouse gas emission rate from coal combustion $e^{comb}_{CO_2}$ was calculated using the specific emission values, $Э_{CO_2}$, $Э_{CH_4}$, $Э_{CH_4}$, EMBED Equation.3 , according to the following relationship

$$e^{comb}_{CO_2} = Э_{CO_2} + GWP_{CH4} + Э_{CH4} + GWP_{N_2O}Э_{N_2O}. \qquad (2.10)$$

In case of direct fuel combustion in flare boilers, specific emission values can be determined using data from Table A.4 of Annex A. In case of coal combustion in a suspended bed, no domestic data on greenhouse gas emissions are available, therefore foreign data [112], given in Table 2.2, can be used for calculations.

Table 2.2

Specific methane and nitrous oxide emissions from coal combustion in the suspended bed, kg/GJ

Installed capacity of TPP, MW	CH_4	N_2O
< 50	1	150
>50	5	100

Similar methodologies for calculating greenhouse gas emissions from refined products and natural gas are given in Annex *B* and Annex *C*, respectively.

General conclusions

1. Many countries of the world, including Ukraine, have significant potential for the production of biogas from manure of farm animals [1].

2. Mathematical model for efficient use of biomass energy in the global energy economy has been developed and justified that allows choosing the rational configuration of energy equipment and determining the optimal structure of energy consumption and costs of energy generation.

3. The absence of generalized data on the energy balance of biogas plants and methods of economic evaluation does not allow us to make an objective judgment about their efficiency, which hinders the involvement of millions of tons of agricultural animal manure into the national economy (Fig. 2).

4. The cause of climate change is greenhouse gases emitted into the atmosphere as a result of burning fossil fuels. The real ways to reduce these emissions is to conserve energy and to replace fossil fuels with non-conventional energy sources, the most potent at the moment, biomass. The main criteria for choosing a biomass energy technology are economic indicators and the amount of greenhouse gas emission reduction at the same amount of pollutants, such as sulphur oxides, nitrogen, carcinogens. Whereas the economic criteria are known and rather effectively used in practice, the ecological criteria do not permit to compare objectively the technologies and equipment which use different types of biofuel and do not enable to make full account of the influence of type and quality of substituted fuel.

5. The main reason for limiting the use of biomass for energy purposes in Ukraine is that the produced energy is relatively expensive, so it is relevant to look for processes and technologies with low capital and operational costs and low cost of energy production due

to production of co-products. Such technologies include the process of oxidative pyrolysis which allows getting fuel gas with relatively high calorific value, and also coke residue due to the sale of which one can get additional income.

6. One of effective directions of energy use of biomass, is the study of technology of organic processing of waste biomass, carried out in the bioenergy reactor. Preliminary studies allowed to determine the necessary technological parameters for creation of a pilot plant for organic processing of biomass waste. For further development of this process it is necessary to create a pilot plant, conduct experimental studies, determine the relationship of various technological parameters, including the use of mathematical modelling.

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PRINCIPLES OF GOVERNANCE AND CONTROL IN THE STUDY AND USE OF SUBSOIL REGIONAL LEVEL

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Abstract

The article examines the processes of the transition of the Ukrainian economy to the principles of market management, which call for the need to review and improve the system of nature management relations, including property relations in the field of subsoil use, management, protection and control.

In the article the processes of transition of economy of Ukraine are examined he principles of market menage, that cause the necessity of revision and perfection of the system of relations of using nature, including the relations of property in the field of the use of bowels of the earth, their management, guard and control. Key words: natural resources, subsoil, minerals, management, control, subsoil use, mineral raw materials, state control, legislation, law.

Introduction

World experience shows that the basis of the economy and industrial progress of any state is the extraction and use of mineral resources, which are mainly located in the subsoil.

The main mineral resources of the Earth are contained in its stratum and are united under the common name "subsoil". Some resources are in the upper layers of the globe, some are on its surface. Mineral resources belong to the category of non-renewable resources. Their total stocks decrease as they are used. The non-renewability of mineral resources is relative, since geochemical processes occurring in the Earth's crust lead to the formation of new compounds that can be used by humans, especially after moving them closer to the Earth's surface. However, the creation of new mineral resources is usually so slow that it practically cannot be taken into account.

Therefore, in our opinion, at the current stage, the question of raising the general level of social and economic development of society is relevant, which is inevitably accompanied by an increase in the consumption of non-renewable natural and mineral resources, intensive development of mineral deposits, an effective legal framework for improving the mechanism of regulation, management and control of social relations in the process use and protection of subsoil.

The delay in reforms in the field of legal relations of use and subsoil protection affects the pace of implementation of progressive ideas of environmental legislation. Those changes and additions to the legislation on subsoil, which have already taken place in relation to certain types of subsoil use , compensate for the lag in reforming the mechanisms for realizing the legal rights and interests of subjects of subsoil use , but do not allow to fully resolve legal conflicts, as from the point of view of ensuring the environmental orientation of the legislation on of the subsoil, as well as state guarantees of implementation of the opportunities established by this legislation for subsoil users .

Formulation of the problem

Theoretical and practical aspects of state management and control over the study and rational use of minerals that lie in the bowels of Ukraine, and in particular in the Rivne -Volyn region, have been studied in the works of such scientists and economists as Danylyshyn B., Gaman P., Metalidi V., Gubanov S., Koretskyi M., Malanchuk Z., Gurskyi D., Andreytsev V., Gozhik P., Patalakha E., Pinchuk N. and others. However, regardless of the received scientific work on this issue, the main principles of state management in subsoil use at the regional level are insufficiently covered. In this regard, the purpose of this work is the need for a comprehensive study of the problems of state management, control and legal regulation of the use and protection of subsoil in order to improve the legislation on subsoil and the practice of its application, which will ensure the economic sustainability of mining enterprises.

Presenting main material

Modern society is well aware of the extreme importance of protection of the environment, which is carried out at different levels and with involvement numerous mechanisms. Regulation of industrial and economic influence human activity on the environment is impossible without the implementation of the management process nature protection, which was separated from the general management structure.

Environment (environment) – the environment in which it functions organization, covering atmospheric air, water bodies objects, land plots, natural resources, flora, fauna, people, as well as interactions connections between them (DSTU ISO 14001:2006).

The specified standard considers the impact on the environment as any change in environment, favorable or unfavorable, which is wholly or partially caused environmental aspects of the organization. At the same time, the environmental aspect of the organization - an element of the organization's activity or its products or services that has or can have a significant impact on the environment.

Environmental protection. Environmental protection, of course environment (environmental protection / control / conservation) is considered as a set of types of protection of the socio-economic and natural environment, which include all their forms surrounding man. They include the complex international, state, regional and local (local) administrative-economic, technological, political, legal and public events aimed at ensuring socio-economic, cultural-historical, physical, chemical and biological comfort, which necessary to maintain human health.

Problems of environmental deterioration and the need for activation activities aimed at reducing the anthropogenic load on the natural environment environment today are relevant and widely discussed in society. Effective management of environmental protection activities in each from the branches of the national economy is a guarantee of environmental safety and economic growth of the state. That is why the topic of improving methods management of environmental protection activities is relevant today.

The purpose of this work is the study of basic management methodsenvironmental protection activities and the formation of proposals regarding them improvement in Ukraine.

Management in the field of nature management is an organizational activity rational use and reproduction of natural resources, protection environment and ensuring the balance of ecological and economic relations.

The main task of management of environmental protection activities is implementation of legislation, control over compliance with environmental safety requirements, ensuring implementation of effective comprehensive measures regarding rational use of natural resources, achieving coherenceactions of state and public bodies, as well as subjects management in the field of environmental protection.

To improve the general mechanism of nature protection management activity is necessary to:

1 - review the standards and methodological basis economic mechanism of environmental regulation;

2 - implement the mechanism annual indexing of regulatory indicators in accordance with volume changes production, inflation rate, producer prices;

3 - reform the system payments for waste disposal by introducing a progressive the nature of payments and their distribution to accumulated volumes;

4 - to introduce a system of economic regulators in the near future nature management, which is based on a combination of tools that first of all, they are economically interested and encourage subjects to implement environmental protection measures and resource conservation measures

It was laid as a basis for the formation of the state environmental policy the basic principle according to which the environmental security of the state becomes important element and component of national security. Provisions that develop this principle was established by a number of laws and documents, incl with the Constitution of Ukraine. Developed by the Ministry of Environmental Protection of natural environment and nuclear safety Concept and Main directions of the state environmental policy of Ukraine in the field of environmental protection natural environment, use of natural resources and provision of environmental safety' defined not only the goal and priority tasks, but also mechanisms for the implementation of tasks, areas of harmonization and integration of environmental policies of Ukraine in the European environmental process.

It is on the basis of this document that Government programs are developed the field of environmental protection and environmental safety. It is already functioning today the program Reserves‘, approved by the Government of the National Program improvement of the Dnipro River, for the implementation of which international aid was involved amounting to more than $5 million, a number of regional environmental programs have been developed.

In accordance with the Basics of national environmental policy‘, it is being improved structure of management of environmental protection activities. Starting with reorganization of the Committee for Nature Protection at the end of 1994 in accordance with the Presidential Decree, a new ministry was formed, whose competence includes all issues of regulation and control in the industry environmental and nuclear safety. For the first time, a modern was formed in Ukraine a management system that corresponds to the experience and practice of developed countries West.

A key place in the system of state management bodies nature management and nature protection is handled by the Ministry of Protection of the natural environment and nuclear safety of Ukraine, the provision of which was approved by the Decree of the President of Ukraine dated February 10, 1995. According to the Regulations, the Ministry of Security of Ukraine is the central body of the state executive power, a sub-department of the Cabinet of Ministers of Ukraine, created for the purpose of implementing state policy in the field of protection natural environment, rational use andreproduction of natural resources, protection of the population and the environment natural environment from the negative impact of economic activity by regulating environmental, nuclear and radiation safety at facilities in all forms of ownership.

The regulations define the tasks, functions, and rights of the Ministry of Health and Safety of Ukraine, the competence of state departments of environmental safety in the regions, in the cities of Kyiv and Sevastopol by specially authorized state bodies executive power in the field of environmental safety of the Autonomous Republic of Crimea, other organizational structures included in its sphere of management, other legal and organizational principles of functioning are foreseen Ministries.

The structure of the central apparatus of the Ministry of Defense. In general reduction of production volumes increases the number of cases of excesses standards for emissions of pollutants into the atmosphere. It is increasing the number of fishing and hunting violations, as well as the number in cases of soil contamination, regimes are not followed nature management in protected areas, violated technologies and rules for felling forest plantations. Deadlines are exceeded operation of sources of ionizing radiation is allowed excessive accumulation of radioactive waste. All this requires increasing the effectiveness of state control in the field of protection natural environment, correction of the situation when whole a number of ministries and departments themselves control their production activities, and a single integral system of state control in the field of nature protection absent.

Projects are envisaged as objects of environmental expertise legislative and normative legal acts, pre-project, project materials, normative-technical and instructional-methodical projects documents, projects for the creation of new equipment, technology, materials, substances, products, the implementation of which may lead to a violation of environmental norms

safety, negative impact on the environment, creating a threat to people's health, as well as the ecological situation.

The norms of the Law determine the forms of public participation in the process environmental expertise and its subject composition. To take into account public opinions of the person conducting the environmental examination (examination subjects) are obliged to hold public hearings or open meetings with participation people. At the same time, the public is given the right to express its opinion regarding the object of examination in mass media, or to submit written comments, suggestions, recommendations to its customers or subjects expertise, or instruct their representatives to work as part of ecological expert commissions and groups.

They are authorized to conduct environmental expertise accordingly Ministry of Environmental and Nuclear Protection security of Ukraine, its ecological expert units or specially created organizations and institutions, organizations and institutions of the Ministry of Health of Ukraine, other executive authorities and their experts formations, public associations, citizens and various institutions, organizations and enterprises, including with the participation of foreign legal entities and individuals, the charters of which provide for the implementation of ecological expert functions. Conclusions of the state environmental examination after approval relevant management bodies in the field of environmental protection of the natural environment and nuclear safety are mandatory.

In Ukraine, management of environmental protection activities is carried out a large number of state management bodies in the field nature management and environmental protection, namely: by the Ministry of Protection natural environment; Ministry of Ecology and natural resources; Department of Protection, Use and Reproduction natural resources; Department of Environmental Safety and Permit System; scientific centers of the above-mentioned ministries, etc.

The management of environmental protection activities is regulated by a number of normative legal acts and laws: ZU "On environmental protection Environment" (1991), Land Code of Ukraine (1992), Law "On Nature Reserve Fund" (1992), Law "On Protection of Atmospheric Air" (1992), Law "About the animal world" (2001), Forest Code of Ukraine (1994), Code of Ukraine about the subsoil (1994), Laws of Ukraine "On the use of nuclear energy and radiation safety" (1995), "About ecological expertise" (1995), "About exclusive (marine) economic zone of Ukraine" (1995), Water Code of Ukraine (1995), Laws of Ukraine "On Disposal of Radioactive Waste" (1995), "About waste" (1998), etc. [3].

There are four groups of environmental protection management methods activity:

1. Administrative methods (setting standards, licensing, certification, environmental quality standards; impact standards on the surrounding natural environment of a certain industrial process).

One of the effective mechanisms that can guarantee environmental safety, in the sphere of state management, environmental protection activities are environmental expertise. According to the Law of Ukraine "On Environmental examination", the purpose of environmental examination is to prevent negative impact of anthropogenic activity on the environment, assessment of the level of ecological security of economic activity and the environmental situation in certain territories and objects.

These methods perform the functions of regulation and control. They designed to curb the production of environmentally dangerous products goods and carrying out eco-destructive activities [2].

However, it should note that enterprises that meet the requirements may not to have an incentive to further reduce the burden on the environment natural environment.

2. Organizational methods (provision of legal and business services, assistance in search for partners, conclusion of agreements under state guarantees; informative infrastructure; initiation of demonstration projects by the state; environmental audit; creation of specialized state research institutes, laboratories, centers, agencies for evaluation of development options production, etc.). The essence of this group of methods is to create favorable conditions for the growth of environmentally friendly production volumes products, development of eco-technologies.

3. Economic methods include tools designed for stimulating desirable types of activities and restraining undesirable ones. So benefits for enterprises are determined by the legislation of Ukraine, which is rational use natural resources and carry out protection measures of the natural environment, as well as for enterprises that carry out innovative activity (including environmentally oriented) [3].

The system of payments for environmental pollution, on the contrary, designed to deter offending activity balance of the ecological system.

So it is one of the most important economic tools environmental protection activity is a fee for environmental pollution natural environment. This fee is paid for emissions of pollutants substances into atmospheric air, discharges of pollutants directly in water bodies and for waste disposal. Its value depends on quantity and harmfulness of pollutants entering the environment natural environment, and separate adjustment coefficients [1].

4. Market methods. With market regulation in the environmental sphere markets are formed for business entities that provide an opportunity firms to buy, sell, trade or redistribute rights to pollution (implementation of the "cap" principle). It should be noted that interesting prospects for the application of this have opened up for Ukraine method after signing the Kyoto Protocol, but our country is not too much actively uses this possibility [2].

As the results of the study showed, despite close attention to environmental problems on the part of state and public bodies organizations and society - management of environmental protection activities in Ukraine is carried out quite inefficiently.

So, for example, according to the Ministry of Ecology, in 2011 on the territory of Ukraine there were 667 solid household waste landfills, of which 36% were not met sanitary standards or were overcrowded. The worst situation on landfills of Kirovohrad, Cherkasy, Chernihiv regions andSevastopol. Meanwhile, there is not a single waste processing plant in Ukraine, and there are only two incineration plants in Kyiv and Dnipropetrovsk.

In 2011, Ukrainian enterprises emitted 4.4 million tons into the atmosphere pollutants: 95.7 each kg for every Ukrainian. In the European Union this one the indicator is 52 kg [4].

As part of the administrative reform, a reduction in the number of employees is foreseen structures responsible for ecology - the State Agency of Forest Resources and of water management, the State Ecoinspection, the State Sanitary Epidemiological Service with the simultaneous establishment of monitoring environment using space satellites. So convenient monitor deforestation or illegal construction. However, given technology does not allow determining the chemical composition of water or air, which can lead to significant problems related to delayed diagnosispossible violations.

There is almost no economic mechanism in the existing system either there are mechanisms for lending nature protection measures, preferential ones taxation and price incentives.

To improve the general mechanism of nature protection management activity is necessary to:

1 - review the standards and methodical base economic mechanism of environmental regulation;

2 - implement the mechanism annual indexing of regulatory indicators in accordance with volume changes production, inflation rate, producer prices;

3 - reform the system payments for waste disposal by introducing a progressive the nature of payments and their distribution to accumulated volumes;

4 - to introduce a system of economic regulators in the near future nature management, which is based on a combination of tools that first of all, they are economically interested and encourage subjects

to implement environmental protection measures and resource conservation measures

State control of compliance with environmental legislation. Improvement of environmental legislation. Standardization and rationing in the field of environmental protection. State ecological monitoring. Environmental and economic reform in Ukraine. Regulation of nuclear and radiation safety in Ukraine/

As the experience of the advanced countries of the world shows, it is quite difficult to carry out an effective environmental policy in the state, even under the conditions of a prosperous economy. The problem of environmental protection in Ukraine seemed all the more difficult to the new state, which is experiencing a deep systemic crisis. Nevertheless, environmental reform in Ukraine began almost simultaneously with the declaration of independence.

The formation of the state environmental policy was based on the basic principle according to which the environmental security of the state becomes an important element and component of national security. Provisions developing this principle were established by a number of laws and documents, including the Constitution of Ukraine.

Developed by the Ministry of Environmental Protection and Nuclear Safety, the Concept and Main Directions of the State Environmental Policy of Ukraine in the Field of Environmental Protection, Use of Natural Resources, and Ensuring Environmental Safety determined not only the goal and priority tasks, but also the mechanisms for the implementation of tasks, the directions of harmonization and integration of environmental policy of Ukraine in the European environmental process.

It is on the basis of this document that Government programs in the field of environmental protection and environmental safety are developed. To date, the Reserves program is already functioning, the Government has approved the National Program for the Improvement of the Dnipro River, for the implementation of which international aid in the amount of more than $5 million has been involved, and a number of regional environmental programs have been developed.

In accordance with the Fundamentals of the National Environmental Policy, the management structure of environmental protection activities is being improved. Starting with the reorganization of the

Committee for Nature Protection (1991), at the end of 1994, in accordance with the Presidential Decree, a new ministry was formed, which is responsible for all issues of regulation and control in the field of environmental and nuclear safety. For the first time in Ukraine, a modern management system was formed that corresponds to the experience and practice of developed Western countries.

The years 1991-1996 were the years of formation of the basic principles of environmental legislation of an independent state. A number of Laws of Ukraine were developed and adopted in the field of environmental and nuclear safety regulation of the use of natural resources for environmental protection. In general, a separate branch - environmental law - has been formed, on the basis of which the practical implementation of environmental reform is carried out. (From the report of Yu. Kostenko, Minister of Environmental Protection and Nuclear Safety of Ukraine).

The Ministry of Environmental Protection and Nuclear Safety of Ukraine occupies a key place in the system of state bodies for management of nature use and nature protection, the provision of which was approved by the Decree of the President of Ukraine dated 10.02. 1995.

According to the Regulation of the Ministry of Safety and Security of Ukraine, it is a central body of state executive power, a subdepartment of the Cabinet of Ministers of Ukraine, created for the purpose of implementing the state policy in the field of environmental protection, rational use and reproduction of natural resources, protection of the population and the environment from the negative impact of economic activity by regulating environmental nuclear and radiation security at facilities in all forms of ownership.

The regulation defines the tasks of the legal functions of the Ministry of Safety and Security of Ukraine, the competence of state departments of environmental safety in the regions of the cities of Kyiv and Sevastopol, specially authorized bodies of state executive power in the field of environmental safety of the Autonomous Republic of Crimea, other organizational structures that are included in its sphere of management, and other legal and organizational principles of the functioning of the Ministry are provided for .

Management in the field of protection and use of subsoil is a way of organizing the activities of the relevant bodies in order to ensure the implementation of the legal norms of the mining legislation and the regulation of social relations in the specified field. It is characterized by the presence of subjects, objects of management, as well as management functions [1].

of subsoil use relations is to ensure reproduction of the mineral and raw material base, its rational use and protection of subsoil.

The tasks of state administration are:

- determination of the volumes of extraction of the main types of minerals for the current period and for the future in Ukraine as a whole and by regions;

- ensuring the development of the mineral and raw material base and preparation of the reserve of subsoil areas, which are used for the construction of underground structures not related to the extraction of minerals;

- setting quotas for the supply of extracted mineral raw materials;

- introduction of fees (payments) related to the use of subsoil, as well as regulation of prices for certain types of mineral raw materials;

- establishment of standards (norms, rules) in the field of geological study, use and protection of subsoil, safe conduct of works related to the use of subsoil.

It is customary to divide state administration bodies in the field of subsoil use and protection into general and special state administration bodies.

Bodies of general state management in the field of subsoil use and protection are authorized bodies of the state executive power, which, along with general powers in the field of socio-economic development of the state, are also entrusted with the functions of ensuring the study, effective use and protection of subsoil. Such bodies, in particular, are: the President of Ukraine; National Security and Defense Council of Ukraine; Cabinet of Ministers of Ukraine; Council of Ministers of the Autonomous Republic of Crimea; regional, district and city state administrations.

Bodies of special state management of subsoil use relations are specially authorized bodies of the central executive power that implement management functions in the field of exploration, use and protection of subsoil, ensuring the safety of work when using subsoil, protecting the rights of subsoil users, protecting the natural environment from pollution related to subsoil use etc.

Bodies of special competence, which perform the functions of state management in the field of exploration, use and protection of subsoil, are divided into two main types according to the nature of their tasks and activities: inter-branch and branch (departmental).

Such bodies are, in particular, bodies of supra-departmental management and control in the field of ecology — the Ministry of Natural Resources of Ukraine, the Ministry of Health of Ukraine, the Ministry of Emergency Situations and in matters of population protection from the consequences of the Chernobyl disaster; bodies of specialized natural resource and industry management — the State Committee for Natural Resources of Ukraine, the Ministry of Fuel and Energy of Ukraine, etc.

The right to use the subsoil is a type of nature use right. This is one of the institutions of environmental law, which is formed in the system of mining law, has its own characteristics, includes a set of legal norms that regulate the grounds and procedure for the emergence, changes and termination of the right of subsoil use, the rights and obligations of subsoil users [2] .

Subjects of the right to use subsoil according to Art. 13 of the Code of Ukraine on Subsoil can be enterprises, institutions, organizations, citizens of Ukraine, as well as foreign legal entities and citizens. That is, subjects of the right to use subsoil in Ukraine are recognized as persons who have acquired the right to use subsoil in accordance with the procedure established by law and, in connection with this, have the corresponding rights and obligations regarding geological study, rational use of subsoil and their protection.

The objects of the right to use subsoil are specific legally separated (defined) subsoil areas, fixed on the right of use for certain subjects.

All subjects of the right to use subsoil have the right:

- carry out geological study, complex development of mineral deposits and other works in accordance with the conditions of a special permit (license) on the subsoil area provided to them;

- dispose of mined minerals, unless otherwise provided by legislation or the conditions of a special permit (license) and a production sharing agreement;

-to carry out conservation of a mineral deposit or its part provided for use under the terms of a special permit (license);

- the right to a priority extension of the period of temporary use of the subsoil.

The basic duties of subsoil users according to Art. 24 of the Code of Ukraine on Subsoil belong to:

- use of subsoil in accordance with the purposes for which it was provided;

- ensuring the completeness of geological study, rational, comprehensive use and protection of subsoil;

- ensuring the safety of people, property and the natural environment;

- bringing the land plots disturbed during subsoil use into a condition suitable for their further use in public production;

- fulfillment of other requirements regarding the use of subsoil, established by the legislation of Ukraine.

The use of subsoil on the territory of Ukraine, its continental shelf and the exclusive (marine) economic zone is subject to payment.

The payment is made in the form of payments for the use of subsoil; deductions for geological exploration works at the expense of the state budget; fee for issuing special permits (licenses) and excise duty. Payments can be made as one-time contributions or regular payments, determined according to the relevant ecological and economic calculations, depending on the economic and geographical conditions and the size of the subsoil area, the type of minerals, the duration of the work, the state of the geological study of the territory and the degree of risk.

The norms of the fee for the use of subsoil and the procedure for its payment are established by the Cabinet of Ministers of Ukraine.

Fees for the use of subsoil can be paid both in the form of cash payments and in kind (part of mined mineral raw materials or other manufactured products, performance of works or provision of other services), except for radioactive raw materials and products of their processing, precious metals, diamonds and precious stones , materials and services of a defense and military nature, as well as information classified as a state secret (Article 32 of the Code of Criminal Procedure of Ukraine) On approval of the list of materials, products and services that cannot be used as payment for the use of subsoil.

Reasons for the emergence of the right to use subsoil. Subsoils are provided for use by enterprises, institutions, organizations and citizens only if they have a special permit (license) for the use of a subsoil plot. Special permits within specific areas are granted to specialized enterprises, institutions and organizations, as well as to citizens who have the appropriate qualifications, material, technical and economic capabilities for subsoil use. A license is issued upon application by a business entity. The granting of such permits is carried out after prior agreement with the relevant local council on the issue of providing a land plot for the specified needs, except for cases when there is no need to provide a land plot. Licenses for the use of subsoil are granted by the State Committee of Natural Resources of Ukraine in agreement with the relevant ministries and agencies, as a rule, on a competitive basis in accordance with the procedure established by the Cabinet of Ministers of Ukraine On approval of the Procedure for granting special permits for the use of subsoil: Resolution of the Cabinet of Ministers of Ukraine dated October 2, 2003 No. 1540 [3].

Grounds and procedure for terminating the right to use subsoil. The right to use the subsoil may be terminated (in whole or in part), suspended for some time due to the grounds stipulated by the current legislation. The grounds for termination of the right to use the subsoil are provided for in Art. 26 of the Code of Criminal Procedure of Ukraine.

The right to use subsoil is terminated in the event of:

1 - if there is no need to use the subsoil;

2 - expiry of the established period of subsoil use;

3 - termination of activities of subsoil users to whom they were provided for use;

4 - the subsoil using methods and methods that negatively affect the state of the subsoil, lead to pollution of the natural environment or harmful consequences for the health of the population;

5 - use of subsoil not for the purpose for which it was provided, violation of other requirements provided for by a special permit for the use of a subsoil plot;

6 - started using the subsoil for two years, and for oil and gas promising areas and oil and gas deposits - 180 calendar days , without valid reasons ;

7 - removal in accordance with the procedure established by law of the subsoil plot provided for use.

The right to use the subsoil is terminated by the body that provided the subsoil for use, and in the cases provided for in clauses 4, 5, 6 of this article, in case of disagreement of the users, by court procedure. At the same time, the issue of termination of the right to use a land plot is resolved in accordance with the procedure established by land legislation. The legislation of Ukraine may provide for other cases of termination of the right to use subsoil.

Landowners and land users may be deprived of the right to extract minerals of local importance, peat and fresh underground water and the right to use the subsoil for economic and household needs in the event of their violation of the order and conditions of use of the subsoil on the land plots granted to them for ownership or use by local councils or other special by authorized bodies in accordance with the procedure provided for by the legislation of Ukraine.

Environmental legislation also provides for cases of suspension (temporary ban) and restriction of the right of subsoil use . This means a temporary ban on subsoil use until the necessary environmental protection measures are implemented, that is, subsoil use is stopped.

The limitation of the right of subsoil use is cases when for a certain period (before the implementation of the necessary environmental protection measures) reduced volumes of emissions and discharges of polluting substances are established both in the enterprise as a whole and in its individual production units.

Subsoil use is limited or temporarily prohibited (stopped) in the event that subsoil users exceed the limits of subsoil use, violate environmental regulations and standards, as well as environmental safety requirements in specially provided cases. in case of their violation of the legislation on environmental protection [4].

The right to use the subsoil is terminated, limited or stopped by the State Committee of Ukraine for the supervision of labor protection or local councils, which provided the subsoil for use by canceling the mining permit of the act and withdrawal of the mining right-of-way in kind, as well as by the State Committee of Natural Resources of Ukraine by canceling the granted license.

The right of subsoil use is divided depending on the terms according to Art. 15 of the Code of Ukraine on Subsoil: permanent (without a predetermined term) and temporary. The temporary right of subsoil use, in turn, is divided into short-term - up to five years and long-term - up to twenty years.

The period of subsoil use begins from the date of receipt of a special permit for subsoil use, unless otherwise provided for in it.

According to the prescription of Art. 6 of the Law of Ukraine "On the State Geological Service of Ukraine" dated November 4, 1999 No. 1216-ХИУ, such permits for the use of subsoil areas, decision-making on their termination or cancellation are granted by the authorized central executive body for geological study and use of subsoil. This regime introduced a mechanism for state control to ensure rational, comprehensive use of the subsoil in order to meet the needs for mineral raw materials, other needs of public production, guarantee the safety of people, property and the natural environment [5]. The main classification feature of the division of the right to use subsoil into types is the purpose of their use. The content of the rights and obligations of subsoil users, subject composition and other issues of legal regulation of relevant relations depend on it. According to Art. 14 of the Code of Criminal Procedure of Ukraine distinguish the following types of use:

- geological study, including research and industrial development of minerals of national importance;
- mining of minerals;
- construction and operation of underground facilities not related to the extraction of minerals, including facilities for underground storage of oil, gas and other substances and materials, disposal of harmful substances and production waste, waste water discharge;
- creation of geological territories and objects of important scientific, cultural, sanitary and health importance (scientific training grounds, geological reserves, nature reserves, natural monuments, medical and health facilities, etc.);
- satisfaction of other needs (Article 14 of the Code of Ukraine on Subsoil) [6].

Each type of subsoil use can have corresponding subtypes. For example, the extraction of minerals can be divided into the extraction of common and non-common minerals.

The Ministry of Environmental Protection of Ukraine is a specially authorized body of the executive power for geological study and ensuring the rational use of subsoil. The main tasks of the specified body are to ensure the implementation of state policy in the field of geological study and rational use of subsoil; ensuring the development of the mineral and raw material base, organization of geological, geophysical, geochemical, hydrogeological, engineering-geological and ecological-geological subsoil research, search and exploration of minerals on the territory of Ukraine, within the territorial waters, continental shelf and exclusive (marine) economic zone of Ukraine , rational use of subsoil; implementation of state monitoring of the geological environment and mineral and raw material base, conducting ecological and geological research; implementation of state control over geological study of the subsoil, participation in the implementation of state control and supervision over the protection and use of the subsoil. The Ministry of Emergencies and Protection of the Population from the Consequences of the Chornobyl Catastrophe, the State Supervision and Protection of Labor of Ukraine, which is a specially authorized central body of the executive power, which carries out state normative regulation of issues of ensuring industrial safety on the territory of Ukraine, also belongs to the special bodies that regulate mining relations. , as well as special permitting supervisory and control functions. The main task of this body is the organization and implementation on the territory of Ukraine of industrial safety and state supervision of all subsoil users and compliance with the requirements for the safe conduct of work in industry; implementation of mining supervision; development and implementation of measures for the prevention of industrial injuries, etc. Territorial geological administrations and trusts are established in the regions of Ukraine, where prospecting and geological work is carried out, the boundaries of which often do not coincide with the boundaries of administrative districts and regions. The procedure for organizing search and reconnaissance works is determined by the instructions and regulations of the Ministry of Natural Resources of Ukraine. Some functions in the field of management of subsoil use relations in Ukraine are entrusted to departments of extractive industries (coal, oil and gas extraction, etc.) [7].

Control in the field of subsoil use and protection is one of the functions of state management of the quality of the environment, a system of measures aimed at organizing the monitoring of the geological environment, checking compliance by individuals and legal entities with the requirements and rules regarding rational subsoil use, subsoil protection and ensuring environmental safety . State control in the field of protection of subsoil and mineral resources can also be considered as an activity of authorized state bodies to verify compliance by all natural and legal entities with the requirements of natural and mining legislation and the application of measures to prevent offenses in this field. Regarding this kind of activity of state bodies, the term supervisory activity is often used , so the question of distinguishing between supervision and control arises.

In the legal literature, there is no clear separation of control and supervision in the field of public administration. According to A.I. Zhmotova's control is characterized by a deep penetration into operational and service activities and includes the verification of the actual result and the application of measures based on the results of the verification. Supervision is mainly aimed at identifying facts of offenses and implementing measures to eliminate them. Thus, the concept of control is broader than the concept of supervision. Supervision is a constituent part, an element of control. Control in the field of environmental protection and use of natural resources includes supervision of compliance with the requirements of environmental and natural resource legislation. It is possible to separate control and supervision according to the forms of the control process. Informational and warning form corresponds to control, and supervision — warning and punitive [8].

Environmental control is a subsystem in the management of the quality of the natural environment, the elements of which are controlled social relations, control methods and criteria, legal means and control bodies. A type of environmental control is control in the field of use and protection of subsoil. Its specificity is determined by controlled social relations. The most important features of legal relations are determined by their object. Regarding environmental and natural resource legal relations, natural objects with such characteristics as natural origin, existence within natural ecological systems in close relationship with other natural objects act in this capacity. Such signs also include the ability to perform life-sustaining functions or socio-economic significance [9].

State control over the use and protection of subsoil within their competence is carried out by councils, state executive bodies on the ground, the Ministry of Natural Resources of Ukraine, the Ministry of Emergency Situations and in matters of population protection from the consequences of the Chernobyl disaster and their bodies on the ground (Article 61 of the Code of Ukraine on Subsoil). State control over the geological study of the subsoil (state geological control) is carried out by the Ministry of Natural Resources of Ukraine and its local bodies. The bodies of state geological control check the implementation of state programs of geological exploration works, the use of decisions on the methodological support of works on the geological study of the subsoil, the validity of the use of methods and technologies, the quality, complexity, effectiveness of the works on the geological study of the subsoil, the completeness of the initial data on the quantity and quality of reserves of the main and co- occurring minerals, timeliness and correctness of state registration of works on geological exploration of the subsoil, availability of special permits (licenses) for the use of subsoil and fulfillment of the conditions stipulated by them; implementation of the decisions of the State Commission of Ukraine on Mineral Reserves; compliance during experimental exploitation of mineral deposits with technologies that would ensure the necessary study of them; preservation of exploratory mining works and wells for the development of mineral deposits, as well as geological documentation, rock samples, duplicate samples that can be used during further exploration of the subsoil.

Bodies of state geological control, within their competence, ensure the solution of other issues related to the geological study of the subsoil.

State geological control bodies have the right to: a) stop all types of work on the geological study of the subsoil, which are carried out in violation of standards and rules and may cause deterioration of deposits, a significant decrease in the efficiency of work or lead to significant losses; b) stop the activities of enterprises and organizations engaged in geological exploration of the subsoil without special permits (licenses) or in violation of the conditions stipulated by these permits; c) to issue mandatory instructions (prescriptions) on the elimination of deficiencies and movements during the geological study of the subsoil. In accordance with the legislation of Ukraine, state geological control bodies may be granted other rights to prevent and stop violations of the rules and norms of geological exploration of the subsoil.

The task of state supervision over the safe conduct of works related to the use of subsoil is to ensure compliance by all subsoil users with the legislation, approved in the prescribed manner, standards, norms, rules for the safe conduct of works, prevention and elimination of their harmful effects on the population, the natural environment, buildings and buildings, as well as on the protection of subsoil.

State supervision over the safe conduct of works related to the use of subsoil is entrusted to state mining supervision bodies, which carry out their activities in cooperation with state geological control bodies, nature protection and other control bodies, and professional unions. State supervision over the conduct of works on the geological study of the subsoil, their use and protection, as well as the use and processing of mineral raw materials (state mining supervision) was carried out by the State Supervision and Protection of Labor of Ukraine and its local bodies in accordance with the Regulation on the Procedure for State Mining Supervision, approved by a resolution of the Cabinet of Ministers of Ukraine dated February 21, 1995. Currently, these functions are the competence of the Ministry of Emergency Situations and in matters of population protection from the consequences of the Chernobyl disaster.

In addition, industrial control over the use and protection of subsoil by enterprises, institutions and organizations (subsoil users) under the jurisdiction of the relevant bodies is carried out.

Subsoil protection is an objective necessity to ensure the interests of the current and future generations of the people of Ukraine.

The main requirements in the field of subsoil protection are: provision of a complete and comprehensive geological study of the subsoil; compliance with the procedure for providing subsoils for use established by law and preventing arbitrary use of subsoils; rational extraction and use of reserves of minerals and their components; prevention of harmful effects of works related to the use of subsoil on the preservation of reserves of minerals, workings and wells that are exploited or conserved, as well as underground structures; protection of mineral deposits from flooding, waterlogging, fires and other factors affecting the quality of minerals and the industrial value of deposits or complicating their development; prevention of unreasonableness and arbitrary development of areas of mineral deposits and compliance with the procedure established by law for the use of these areas for other purposes; prevention of subsurface pollution during underground storage of oil, gas and other substances and materials, burial of harmful substances and production waste, discharge of wastewater; compliance with other requirements stipulated by the legislation on environmental protection (Article 56 of the Code of Ukraine on Subsoil) [10].

Responsibility for violations of the legislation on subsoil in environmental law is an important component of the legal provision of rational nature management, restoration of ecological objects and environmental protection, which, in turn, aims to punish the guilty, stop and prevent violations of legislation in the field of nature management and environmental protection natural environment, as well as renewal of violated rights of owners of natural resources and nature users , etc.

Violation of the legislation on subsoil entails disciplinary, administrative, civil and criminal liability.

According to Art. 65 of the Code of Ukraine "On Subsoil", liability for violation of legislation on subsoil occurs when:

- arbitrary use of subsoil; violation of norms, rules and requirements regarding the conduct of works on the geological study of the subsoil;
- violations of the rules and requirements for carrying out work on the geological environment;
- selective production of rich areas of deposits, which leads to excessive losses of minerals;
- excessive losses and deterioration of the quality of minerals during their extraction;
- damage to mineral deposits that completely exclude or significantly limit the possibility of their further exploitation;
- violation of the established order of development of mineral deposit areas;
- failure to comply with the rules of subsoil protection and requirements for the safety of people, property and the natural envi-

ronment from the harmful effects of works related to the use of subsoil;

- destruction or damage to geological objects of special scientific and cultural value, observation regime wells, as well as surveying and geodetic signs;
- illegal destruction of surveying or geological documentation, as well as duplicate samples of minerals, necessary for further geological study of the subsoil and development of deposits;
- failure to comply with the requirements for bringing the mine workings of wells that have been liquidated or conserved to a state that guarantees the safety of people, as well as the requirements for preserving the deposits of mine workings and wells during conservation, - are subject to disciplinary, administrative, civil and criminal liability in accordance with by the legislation of Ukraine (Article 65 of the Code of Ukraine on Subsoil).

An important element of the legal regulation of the use and protection of subsoil is environmental liability for violations of the relevant legal framework. There are two forms of such responsibility — economic and legal. The basis of economic responsibility is the fact of causing damage to the surrounding natural environment by lawful activity (emissions of pollutants within the permitted limits), while legal (environmental-legal) responsibility is based on the fact of an offense. However, in the first case, we are talking about the special use of atmospheric air, subsoil, and water for the emission or disposal of pollutants (just as the water legislation — Article 48 of the Water Code of Ukraine — defines special water use as the withdrawal of water from water bodies and discharge into them return waters). The procedure for using natural objects for the specified purposes requires obtaining a special permit (license), compliance with environmental standards for the content of toxic substances in emissions, and charging a fee for special use.

State administration bodies in Ukraine are divided into three branches of government: representative, executive and judicial. By level, state administration is divided into: state (the Verkhovna Rada of Ukraine, the Cabinet of Ministers of Ukraine, the Supreme Court of Ukraine), regional (regional councils, regional administrations, regional bodies of justice) and local (district councils and councils of OTG, self-governing bodies of OTG, judicial power at places).

At the state level (CMU), all ministries and agencies related to the management, use, and control of natural resources are involved in the UPC. The Ministry of Environmental Protection and Natural Resources of Ukraine is the central state body of Ukraine, which ensures the coordination of the activities of branch agencies regarding the Code of Civil Procedure. It implements the implementation of the following: the implementation of the state environmental and scientific-technical policy, aimed at preserving the living and non-living nature of the NPS, which is safe for existence, protecting the life and health of the population from the negative impact caused by the pollution of the NPS, achievement of stable socio-economic development and harmonious interaction of society and nature; implementation of administrative and ecological and economic measures with the aim of creating a system for preventing the negative impact of economic and other activities on the NPS, eliminating the consequences of such impact, objectively informing the population about the ecological state of the environment; state control over compliance with environmental safety norms and rules, use, protection and reproduction of natural resources, rules for storage, transportation and use of toxic and other hazardous substances and materials, as well as industrial and household waste; comprehensive management and regulation in the field of environmental safety, protection of natural resources and rational use and reproduction of natural resources, coordination of the activities of central bodies of state executive power, enterprises, institutions and organizations, as well as approval of draft regulations issued by specially authorized central bodies of state executive power regarding regulation of relations in this field; organization of development and substantiation of projects of targeted state programs and formation of a state order, conclusion of contracts for this purpose on behalf of the government and coordination of the activities of enterprises, institutions and organizations related to the solution of this order, implementation of other measures of environmental direction carried out at the expense of the state budget and other sources of funding; ensuring Ukraine's participation in international cooperation on environmental issues and fulfillment of obligations arising from Ukraine's international agreements, as well as protection of Ukraine's environmental interests.

At the regional level, the executive power manages individual natural objects, the size of which exceeds the size of administrative regions. For example, the State Agency for Water Management manages the use of river waters according to the basin principle (through the Dnipro, Dnistrovsk, Yuzhno-Buzka, and other basin water management associations). The Ministry of Environmental Protection and Natural Resources of Ukraine has state inspections for the protection of the Black and Azov Seas. At the local level, on the scale of the oblast, city, and district, a double UPC is carried out - on the one hand, by local units of ministries (and above all, the Ministry of Ecology), on the other - by the executive power of the relevant territory. Control over the implementation of environmental legislation is carried out by environmental protection bodies - courts, prosecutor's office, SBU, police - within the state, regions and other administrative-territorial units.

In local united territorial communities, depending on the number of deputies, there may be commissions or groups of deputies that deal with issues of nature management in their territory. In particular, they develop drafts of territorial resolutions, rules, individual regulations, which are adopted at the session of the relevant Council. For the practical implementation of laws, decisions and other documents adopted by representative (legislative) authorities, it is necessary to develop a number of working documents (resolutions, orders, programs, etc.), organize and control their implementation. These tasks are included in the functional responsibilities of the executive branch of government.

The central special state body responsible for rational nature management is the Ministry of Environmental Protection and Natural Resources of Ukraine (Ministry of Natural Resources of Ukraine), which was restored on May 27, 2020 (https://cutt.ly/kuS50J00). It repeatedly changed its name, structure and functional duties. For the first time, such a Ministry was established on the basis of the former Nature Protection Committee of the Ukrainian SSR immediately after the collapse of the Soviet Union and the declaration of Ukraine's independence. Currently, the Ministry of Natural Resources of Ukraine forms and implements state policy in the field of:

- environmental protection,

- environmental and, within the limits of the powers provided by law, radiation, biological and genetic safety,
- in the field of fishing and fishing industry,
- protection, use and reproduction of aquatic biological resources,
- regulation of fishing and navigational safety of fishing fleet vessels,
- forestry and hunting farms.

At the same time, it ensures the formation and implementation of state policy in the field of:

• development of water management and hydrotechnical land reclamation, management, use and reproduction of surface water resources;

• geological study and rational use of subsoil;

• management of the exclusion zone and the zone of unconditional (mandatory) resettlement, overcoming the consequences of the Chernobyl disaster, decommissioning the Chernobyl nuclear power plant and transforming the "Shelter" facility into an environmentally safe system, as well as the implementation of state management in the field of radioactive waste management at the stage their long-term storage and burial;

• implementation of state supervision (control) in the field of environmental protection, rational use, reproduction and protection of natural resources;

• implementation of state geological control, as well as in the field of preservation of the ozone layer, regulation of the negative anthropogenic impact on climate change and adaptation to its changes, and fulfillment of the requirements of the UN Framework Convention on Climate Change and the Kyoto Protocol to it, the Paris Agreement.

In this area, the Ministry of Natural Resources of Ukraine directs and coordinates the activities of the following central specially authorized bodies of the executive power: the State Geology and Subsoil Service of Ukraine ("Derzhgeonadra"), the State Agency of Water Resources of Ukraine, the State Agency of Forest Resources of Ukraine, the State Agency of Fisheries of Ukraine, the State Service of emergency situations, the State Environmental Inspection of Ukraine and other institutions that have special powers to manage the use of natural resources.

Among the state authorities, the following departments are endowed with separate powers in the field of nature management and environmental protection:

- The State Service of Ukraine for Geodesy, Cartography and Cadastre (State Geocadaster of Ukraine), which is the central body of the executive power in matters of land relations, maintenance of public cadastral digital map, national infrastructure of geospatial data, national geodetic network, topographic digital map, etc.

- The State Agency of Forest Resources of Ukraine – carries out:

- state administration in the field of forestry and hunting, as well as state control over compliance with forestry legislation (except for state control over harmful organisms and plant protection);

- carries out state management of the territories and objects of the nature reserve fund in the forests of enterprises, institutions and organizations belonging to the sphere of its management;

- organizes forest management and hunting management;

- maintains the state forest cadastre and forest accounting;

- performs soil monitoring for the purpose of growing productive forest plantations, forest vegetation, and hunting animals.

The State Agency of Water Resources of Ukraine (State Water Agency) is the central body of the executive power, whose activities are directed and coordinated by the Cabinet of Ministers of Ukraine through the Minister of Environmental Protection and Natural Resources and which implements state policy in the field of water management development, management, use and reproduction of surface water resources.

The State Geology and Subsoil Service of Ukraine (Derzhgeonadra) is the central body of the executive power, which implements state policy in the field of geological study and rational use of subsoil.

The State Service for Emergency Situations (SES) is the central body of the executive power, whose activities are directed and coordinated by the Cabinet of Ministers of Ukraine through the Minister of Internal Affairs and which implements state policy in the field of civil protection, protection of the population and territories from emergency situations.

The State Fisheries Agency of Ukraine (State Fisheries Agency of Ukraine) is the central body of the executive power, the activities of which are directed and coordinated by the Cabinet of Ministers of Ukraine through the Minister of Agrarian Policy

The Cabinet of Ministers of Ukraine, in accordance with the Law of Ukraine "On Environmental Protection", implements the environmental policy determined by the Verkhovna Rada of Ukraine and the President of Ukraine with the help of such functional aspects as: development of state environmental programs, ensuring their implementation; coordination of the activities of ministries and other bodies of the central executive power on issues of environmental protection; making decisions on restrictions, temporary prohibition (suspension) or termination of the activities of enterprises, institutions and organizations in case of their violation of environmental legislation; implementation within the framework of its powers of state administration in the field of protection and rational use of land, its subsoil, water resources, flora and fauna, and other natural resources.

State administrations of regions carry out their activities in accordance with the Law of Ukraine "On Local State Administrations". They ensure the implementation of programs for the protection of the natural environment, the implementation of the powers delegated by local self-government bodies on the provision of land plots for urban planning needs, the organization of the protection of territories and objects of the nature reserve fund of local importance, the elimination of the consequences of environmental disasters, cooperation with local self-government bodies in the field management of nature use and environmental protection.

Local self-government bodies manage nature use and environmental protection in the respective region, guided by the laws "On Local Self-Government in Ukraine" and "On Environmental Protection". The administrative functions of these bodies include: organizing the development of local environmental programs; approval, taking into account environmental requirements, of planning and development projects of settlements, general plans and schemes of industrial facilities; organization of environmental expertise; making decisions on the organization of territories and objects of the nature reserve fund of local significance and other territories subject to special protection; implementation of control over compliance with legislation on environmental protection.

Finally, let's point out the sectoral (departmental) management of nature use and environmental protection. It is about organizing the activities of individual ministries to ensure proper conditions for the use and protection of natural objects that are operated by enterprises and institutions subordinate to it. In particular, the bodies of interdisciplinary competence include:

The Ministry of Agrarian Policy and Food of Ukraine carries out state testing and registration, determines the list of chemical, biological, plant protection and growth regulators, fertilizers approved for use, taking into account the requirements for their safety for human health and the natural environment; carries out state phytosanitary control over compliance with the quarantine regime at the stages of cultivation, processing and sale of plants and products of plant origin.

The Ministry of Development of Communities and Territories of Ukraine (Ministry of Regions) works to increase the competitiveness of regions, develop local self-government, ensure comfortable and safe living conditions for the population of Ukraine, create and comply with effective rules and conditions for construction activities, a harmonious living environment, and effective use of energy carriers in the field of housing and communal services .

The Ministry of Health of Ukraine - the central body of the executive power of Ukraine in the field of health care: ensures the formation and implementation of state policy in the field of health care, combating HIV infection/AIDS and other socially dangerous diseases, ensures the formation and implementation of state policy policy in the field of creation, production, quality control and sale of medicines, medical immunobiological preparations and medical products, in the field of circulation of narcotic drugs, psychotropic substances, their analogues and precursors, countering their illegal circulation, and also ensures the formation of state policy in the field of sanitary and epidemic welfare of the population; also provides sanitary and hygienic protection of the environment, contributes to the optimization of the living conditions of the population, prevents harmful effects on the surrounding natural environment and human health. The work of the once extensive system of the Sanitary and Epidemiological Service of the Ministry of Health of Ukraine, which carries out appropriate state supervision in accordance with the Law of Ukraine "On Ensuring Sanitary and Epidemic Welfare of the Population", is being resumed.

Administrative methods are a set of techniques, influences based on the use of objective organizational relations between people and the general organizational principles of state management of environmental management on the basis of the current environmental legislation (restrictions, prohibitions, regulations, administrative penalties, etc.).

Along with improving the environmental education and education of the population, an important task of the state is to create such conditions for the activities of enterprises under which they would be forced to comply with environmental legislation, greenize technological processes. One of the important mechanisms for achieving these goals is the administrative mechanism. It is based on the establishment of norms, standards, rules of environmental management and relevant planned indicators for environmental protection enterprises and punishments in case of violations. The latter, in terms of the degree of influence on the components of nature, can be: reprimanding, imprisonment, removal from office, imposing a fine on the enterprise and its managers. However, this path is complex and ineffective, as it requires constant monitoring and a significant number of controllers. The amount of fines should provide conditions under which the violation is unprofitable from the point of view of the economic interests of the nature user. As a rule, penalty payments are set in multiples of in relation to the standard indicators of the fee or relative to the amount of lost profits. Payments for excess and irrational use of natural resources (wild plants, animals, mineral mud, water, etc.) in the form of fines are levied on profits that remains at the disposal of the nature user, and from his own funds. Economic incentives are more effective when the state creates conditions for profitability of compliance with environmental legislation, and unprofitability in case of its violation by applying penalties, tax benefits and penalties, etc.

Eonomic mechanism of environmental management

Environmental management processes to achieve determined nature protection goals cause the need to ensure purposeful and coordinated activity of relevant structures. For this theoretical and methodological approaches are developed and applied form the basis of the development and regulation of environmental protection activities at different levels of its implementation. Environmental management is based on principles that meet objectives management, determined by ' ties and relationships that take place in the process management. They are the basis for building management and distribution bodies competencies, tasks related to the activities of management bodies.

The principles of management of environmental protection activities are formulated on basis of ecological regularities of interactions connection of society with the environment the environment and are actualized according to the processes that take place at the same time.

The main principles of management of environmental protection activities have legal basis and are reflected in the relevant regulatory documents. WITH from the point of view of legal aspects, the following basic principles of management are highlighted the field of environmental protection [3]:

- ensuring legality in the implementation of management in this area;
- a combination of complex and differentiated approaches inmanagement of environmental protection;
- a combination of state administration with self-governing and public administration management in this field;
- implementation of basin management;
- software and purpose support for the development and implementation of measures in the field of environmental protection, ensuring environmental safety, rational use of natural resources.

The principle of legality in the implementation of state management in the industry environmental protection means that management bodies in this field, their officials must be guided in the course of their activities by the prescriptions of the legislation, which determine their powers, the procedure for adoption relevant management decisions, as well as the provision of management services ecological nature. State administration bodies must comply environmental requirements for the measures they have to develop with the aim ensuring environmental protection, ecological safety, rational use of natural resources.

The principle of combining complex and differentiated approaches in management of environmental protection. Interdependence natural resources, inseparability of connections in natural processes needs implementation of a unified scientific and technical policy, coordination in this field efforts of all executive authorities, enterprises, institutions, organizations and citizens in the development and implementation of environmental protection measures, use of natural resources, ensuring environmental safety. Complexity involves comprehensive consideration of environmental, economic, technical, social, etc. factors that can affect efficiency environmental protection measures.

The principle of combining state administration with self-governing and public administration management in the field of environmental protection.

Solving environmental problems requires coordinated actions by the authorities state administration and local self-government bodies. Under such circumstances a legal mechanism for the interaction of state administration bodies is created of local self-government bodies and public administration bodies making decisions on certain protection issues at the territorial level natural environment, ensuring environmental safety

The principle of basin management. The Water Code of Ukraine states,that the state administration in the field of water use and protection and restoration of natural resources is carried out according to the basin principle. Him introduction is caused by the ecological and economic importance of rivers basins, which can cover the territory of several administrative territorial units. Within the limits of the river basins, the cycle is closed substances, pollutants spread and accumulate, placement of production facilities is carried out. Basin management creates conditions for managing the river basin as a whole, as well as for balanced use, protection and reproduction of water resources, prevention of violation of the conditions for the formation of water flow, manifestation of harmful effects water.

The principle of software-purpose support for the development and implementation of measures in the field of environmental protection, ensuring environmental safety, rational use of natural resources. This principle is key in this field state administration, allows to connect the goals and objectives of environmental protection for a prospective period with concrete measures aimed at their implementation measures of an organizational, technical, scientific and other nature, resource (financial, material and technical) provision of these measures, and also with the bodies responsible for their development and implementation. Software- the target principle is implemented through the preparation of state environmental programs, sections on environmental safety, environmental protection in the composition state programs of economic and social development of the state and in others program documents.

The best results are achieved by combining economic levers with sufficiently effective control and a higher mechanism of administrative coercion (Fig. 1).

The economic mechanism of environmental protection involves the use of a number of other instruments of influence on the economic interests of enterprises and its individual employees, in particular, such as the ilgo taxation, favorable pricing for environmentally friendly products, and, conversely, fines for environmental pollution and violation of limits, norms, standards.

Previously, nature management was generally free, that is, enterprises used natural resources, as well as polluted the environment for free. Penalties were imposed only with catastrophic consequences of environmental impact, which did not contribute to rational environmental management. Under the system of economic assessments of natural resources understand the system of centrally established standards for the maximum allowable costs for the preservation of this natural good and standards for the minimum permissible efficiency of operation natural resources. The economic assessment of natural resources is a monetary expression of the long-term effect of their exploitation. The valuation of natural resources is necessary for the economic justification of investments in the reproduction, protection and rationalization of the use of natural resources and the choice of the most profitable of the popular darsky positions of means of their disposal.

Fig.1. Scheme of combining administrative and economic mechanisms of nature management [4]

Paid nature management, which provides for payment for almost all natural resources and for environmental pollution, was introduced in the early 90s of the twentieth century. Over-limit use fees and pollution is several times higher than the fee for use and pollution within the established standards (limits). At the same time, the payment of fees for use and pollution does not exempt the natural user from the implementation of environmental legislation. One of the important levers of the economic mechanism of nature management is financing, that is, provision of funds for clearly defined environmental measures. Sources of financing can be budget funds, own funds of enterprises, bank loans and various environmental funds, including. international. The creation of environmental funds is also one of the economic links in the mechanism of environmental management. Environmental funds are formed from the receipt of payments from all environmental enterprises, penalties for violation of environmental legislation, voluntary contributions of enterprises. Funds of environmental funds are used exclusively for their intended purpose for environmental purposes in accordance with the law. A very important factor for solving environmental problems is public opinion, coverage of problems and positive achievements by the media and state support for public initiatives. on the preservation of dundshaft and biological diversity and historical and cultural values.

Carrying out urgent environmental measures, targeted scientific and ecological-educational projects according to the decisions of the Ministry of Environment and representative bodies on the ground. The following economic (incentive and penalty) measures are used:

- establishment of tax benefits (the amount of profit from which the tax is levied is reduced by an amount that fully or partially corresponds to environmental expenditures); exemption from taxation of environmental funds and environmental property;
- application of incentive prices and highs for environmentally friendly products;
- application of preferential lending to enterprises that effectively implement measures in accordance with current environmental legislation;
- introduction of special additional taxation of environmentally harmful products and products manufactured using environmentally hazardous technologies;
- fines for environmental offenses.

Preventive and protective functions in the field of nature management and environmental protection

Control over the use of natural resources and environmental protection is carried out by specially authorized bodies and state executive bodies on ecology and natural resources using the mechanisms of state environmental control (state environmental monitoring), departmental environmental control, public environmental control, environmental expertise, environmental audit, environmental insurance, etc.

1. The function of supervision (monitoring) over the use of natural resources and environmental protection is the activity of authorized state executive bodies on ecology, supervision, collection , pro-

cessing, transmission, preservation and analysis of information on the state of the environment , forecasting its changes and developing scientifically based recommendations for adoption managerial riche

2. Environmental control is the activity of authorized state executive bodies, the purpose of which is to ensure compliance with the requirements of the legislation on environmental protection by all state bodies, enterprises, institutions and organizations, regardless of the form of ownership and subordination, as well as citizens. Depending on the system of bodies exercising environmental control, the following types of control are distinguished : state, departmental, production, public.

State environmental control ensures compliance with the requirements of environmental legislation by all state bodies, enterprises, institutions and organizations, regardless of the form of ownership and departmental subordination and physical persons throughout Ukraine. It is carried out by central and local executive authorities and local self-government bodies.

Departmental control is carried out by ministries and state committees in compliance with the requirements of environmental legislation by enterprises, institutions and organizations subordinate to them.

The implementation of production control is entrusted to special units (departments for nature protection, environmental laboratories) operating in the relevant industrial or other enterprises.

Public environmental control in accordance with Article 36 of the Law of Ukraine "On Environmental Protection" is carried out by public organizations that have responded personnel and equipment or associations of citizens, including. with the scientists involved by them. In addition, environmental control is carried out in certain areas by public hunting inspectors, public inspectors of fish protection, etc.

3. Environmental expertise is the activity of authorized state executive bodies, ecological and expert formations and associations of citizens, based on intersectoral environmental research, analysis and evaluation of pre-design, design and other materials and objects, the implementation or action of which may adversely affect or affect the

state of the environment and human health, directed to prepare conclusions on the compliance of the planned or carried out activities with the norms and requirements of environmental legislation, ensuring environmental safety.

The objects of environmental expertise are draft legislative and other regulatory legal acts, pre-design, design materials, documentation on the creation of new equipment, technology, materials, substances, economic decisions, products, systems and objects, the implementation of which may lead to violation of environmental safety standards, negative impact on the state of the environment. Environmentally hazardous facilities and complexes, including military and defense purposes, as well as environmental situations prevailing in individual settlements, are subject to environmental expertise. points and regions. The list of activities and facilities that pose an increased environmental hazard is established by the Cabinet of Ministers of Ukraine on the proposal of the Ministry of Environment and the Ministry of Health of Ukraine.

According to the Law of Ukraine "On Environmental Expertise" (Article 12), state, public and other types of environmental expertise are carried out. The conclusion of the state environmental expertise after approval by a specially authorized central executive body on environmental protection is mandatory for execution. The conclusions of public and other environmental expertise are of a recommendatory nature and can be taken into account by the bodies that carry out the state environmental expertise, as well as by bodies interested in implementation of design solutions or operate the corresponding object.

4. Environmental audit can be carried out in accordance with the Law of Ukraine "On Environmental Audit" as a function of public administration in the field of environmental management. This is a documented act of verification, including the collection, analysis and objective assessment of materials for compliance with environmental legislation of certain types of activities, activities, conditions, management systems environment. The customer uses the results of such an audit to guide in its activities to comply with current environmental legislation and optimize the impact of activities. Environmental

audit can be voluntary or compulsory, is carried out on the basis of an agreement between the customer and the contractor.

5. Environmental insurance as a management function consists in insuring the liability of business entities (policyholders) whose economic activity poses an increased environmental hazard, in case of causing them damage to third parties due to environmental pollution and deterioration of the quality of natural resources. The basis for the emergence of insurance relations is an environmental insurance contract concluded between the insurer and the insured. The purpose of environmental insurance is full or partial protection of property interests' citizens and legal entities in case of deterioration of the environmental situation as a result of man-made accidents or disasters that caused environmental damage.

Subjects of nature management are specially authorized state bodies, self-government bodies, legal and natural persons-land users, public organizations that actively defend their interests within the framework of nature protection legislation and take responsibility for the use and management of a certain natural component in the specified territory. As for the territories of the nature reserve fund (PZF), which are not disturbed or slightly disturbed by human activity, the legislation prohibits any economic activity in the zones of strict inheritance and allows recreational and limited traditional economic activities of the local population in the buffer zones of the protected areas. In these territories, nature management is carried out by special administrations of protected institutions, which are financed from the state budget.

The management of nature management and protection of the natural environment is practically implemented through the formation of a system of state executive authorities and local self-government in the field of nature management, which ensure the state policy of rational nature management, the achievement of minimizing the negative impact on the natural environment, and ensure the balanced development of the territory. For effective management, information is needed both about the purpose and desired changes in the state of the selected management object, and about real changes in the state of the object in time and space. The received information is the basis for creating a database of necessary data about the object, it must be processed and analyzed in order to identify the direct impacts and develop scientifically based management decisions. This information is provided by the State Environmental Monitoring System (ESMS). The organization and management of nature management monitoring is a complex and multidisciplinary system with various models for assessing the state of natural resources, modeling and forecasting its changes under certain scenarios of use. Among various alternative solutions, the nature user must choose the one that best meets the selected goals and criteria of the PTS management, as well as corresponds to the development strategy of the territorial united communities within which nature use is carried out. The correctness of the adopted management decision will depend on the reliability of the information about the management object and the technologies that will be used.

Conclusions

According to experts and analysis of literary sources, it was established that:

- The main functions of state administration in the field of geological study, use and protection of subsoil are: planning of use and protection of subsoil; state examination and assessment of mineral reserves; state accounting and cadastre of mineral deposits, reserves and occurrences of minerals and the state balance of mineral reserves; legal regulation of distribution and redistribution of subsoil and minerals; state control and supervision of the conduct of works on the geological study of the subsoil, their use and protection of the subsoil; settlement of disputes on the use of subsoil.

- State management and control in the field of protection and use of subsoil is a system of measures (organizational, technical, technological, socio-economic, ecological, legal, etc.) provided by the current legislation of Ukraine, aimed at ensuring rational use of subsoil and mineral resources, prevention of harmful effects works related to the use of subsoil, for the preservation of reserves of minerals, mined workings and wells that are exploited or conserved, as well as underground structures, prevention of harmful effects of mining works on the state of the natural environment, life and health of people.

- The problem of control in the state administration over the study, use and protection of subsoil is closely related to the processes characteristic of the modern stage of state development and a new understanding of the role of state administration. In modern conditions, control plays primarily a regulatory role, but it also has preventive significance. The essence of control is that the subject of management takes into account and checks how the managed object carries out its prescriptions in order to block deviations of activity from the given management program, and in case of detection of violations, to bring the managed system, into a stable state with the help of social regulators.

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THEORETICAL BASIS OF METHODS FOR CALCULATING THE DYNAMIC CHARACTERISTICS OF THE BASES AND FOUNDATIONS OF OIL AND GAS COMPLEX EQUIPMENT

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Abstract

The monograph presents a comparison of mathematical and numerical calculation methods as the most promising in this field. Calculations by the above methods are proposed to be carried out according to the second limit state, that is, according to deformations, to determine the amplitudes of oscillations and settlements of the soil and structures. The mathematical method of dynamic phenomena was investigated using an idealized mathematical apparatus. The case of foundation oscillations is described if the soil exerts elastic resistance to compression and displacement.

Calculations to determine the dynamic characteristics of foundations are recommended to be carried out in two directions: using mathematical equations and using software complexes.

The use of a mathematical method in dynamic calculations allows to describe mathematically with the use of certain assumptions and to determine the dynamic characteristics of object oscillations, foundation settlement, which can be described using formulas. And the software complex using the numerical method of finite elements makes it possible to obtain a complete description of the field of vibration displacements, vibration accelerations, and vibration velocities. At the same time, graphs of the dependence of dynamic characteristics at any point of the calculation scheme on time and a graphic description of the deformed grid were obtained.

1. Introduction

The development of the economic sphere of Ukraine involves a significant increase in production rates at enterprises of the oil and gas complex. This leads to an increase in the number of machines and equipment that exert a dynamic influence on foundations and structures located near industrial facilities.

Today, the design of the reconstruction of the foundations of various machines in accordance with building regulations is carried out according to the analytical expressions of the amplitude of the foundation vibrations, depending on the nature of the dynamic influence. Thus, it is not always possible to assess the dynamic state of the entire foundation and its foundations. Therefore, it is necessary to pay attention to the application of numerical methods in the calculation and modeling of dynamic processes, taking into account the nonlinear behavior of the soil under complex stress conditions.

At the same time, it remains an important task to improve the methods of calculating the parameters of oscillations and settlements during the reconstruction of the bases and foundations of machines. Calculation of these characteristics is carried out on the basis of the simplest soil models, which are unable to sufficiently take into account a number of dynamic factors and soil conditions of the research site. Such methods of determining the amplitudes of oscillations and subsidence do not take into account cracks and damage to the foundations of the equipment, changes in the properties of the soil around the foundation that occurred during operation, physical and mechanical characteristics of the soil of the bearing layer, as well as the underlying layers, which can only be taken into account by numerical methods even at the stage of reconstruction . Therefore, the study of foundations at the stage of reconstruction design, taking into account such features of the "foundation - foundation equipment" system, is quite relevant.

2. Basic investigation

2.1. Basic methods of dynamic calculations of bases and foundations

Calculations to determine the dynamic characteristics of foundations are carried out in two directions:

Dynamic calculations are performed in accordance with the mechanics section "dynamics" using the dynamic characteristics of materials and soils. The Lagrange method is used to derive the equations of motion of the foundation. This method requires a preliminary determination of the value of the mechanical energy of the system. Which consists of the kinetic energy of vertical, horizontal movement and rotational movement and the potential energy of soil shear deformation in the plane of the foundation sole.

If the foundation is buried in the soil, then the potential energy of deformation of the lateral compression of the soil is determined, the reduction of potential energy as a result of lowering the center of gravity of inertia. As a result of the calculations, we have the differential equations of forced planar harmonic vibrations of the foundation, which can be considered generally known in the case of application of transformations.

1. Dynamic loads are converted into static loads using special approaches, and further calculations are carried out in static mode. When considering the system of forces, use the principle of J. D'Alembert. At the same time, inertial forces (U_x,U_z,M) are added to all external forces and the system is considered as being in equilibrium.

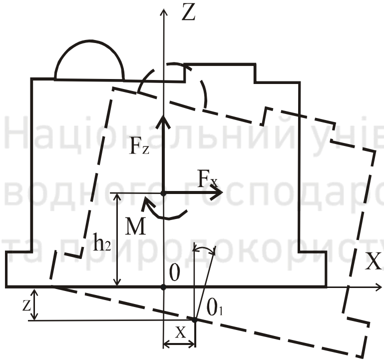

Fig. 1. Calculation scheme of the method of calculating dynamic characteristics

2. This approach is called the kinetostatics method

Both approaches are fair and give an equally correct solution. Consider the application of the kinetostatics method to the derivation of the equations of motion, as the most widespread approach.

We assume that the center of inertia of the foundation and the machine and the center of gravity of the sole are located on the same vertical lying in the main central plane of the foundation. The external loads of the machine, located in the same plane, are brought to the center of inertia of the oscillating mass. They can be represented in the form of an applied force *P* at this point and a pair of forces with a moment M. Let's combine the origin of the coordinates of the system with the center of inertia of the mass of the foundation and the machine, when the foundation is stationary.

Under the action of loads P,M, the foundation will make a planar movement (Fig. 1). The movement of all points of the foundation will be determined by the values of three independent parameters: x, z projections of the displacement of the center of gravity of the foundation on the coordinate axes with the angle of rotation of the foundation relative to the y axis, which passes through the center of inertia of the foundation and the machine perpendicular to the plane of oscillation. We project all the forces acting on the foundation at the moment of time t on the x,z axis, adding to them the projections on the same axes of inertial forces.

Under the action of dynamic loads, the base is assumed to be linearly deformed, ideally elastic-viscous and massless (soil inertia is not taken into account). The viscosity of the base is determined by the damping properties of the soil. The properties of the base are determined by the coefficients of elastic uniform compression C_z for vertical vibrations, elastic uniform displacement C_x for horizontal vibrations, elastically non-uniform compression C_φ and elastically non-uniform displacement C_ψ for rotational vibrations and stiffness coefficients for natural bases under elastic uniform compression K_z, during elastic non-uniform compression K_φ, under elastic non-uniform compression shifts K_x.

The damping properties of the foundation are determined by the characteristics of relative damping during vertical, horizontal, and rotational oscillations relative to the horizontal and vertical axes, which depend on the average pressure under the foundation sole.

The damping properties of the foundation are determined by the characteristics of the relative damping ξ during vertical, horizontal, and rotational oscillations relative to the horizontal and vertical axes, which depend on the average pressure under the sole of the foundation.

Thus, differential equations of forced oscillations of a system with one degree of freedom were obtained [1].

Formulas for determining the amplitudes of forced vibrations of foundations are obtained as a result of solving differential equations.

This approach to the calculation of machine foundations has been used in domestic engineering practice for the past 20 years.

The production technology or the operation of the machine may require control of the amount of settlement of the machine foundation.

The settlement of the machine foundation caused by dynamic load is determined by the method described by O.O. Savinov. by the formula

$$S_d = \sum_{i=1}^{i=n} h_i \frac{\varepsilon_i - \varepsilon_{0i}}{1+\varepsilon_i}, \tag{1}$$

ε_i and ε_{0i} - porosity coefficients of the natural and compacted layer, respectively;

h - the depth of the soil layer with the same porosity coefficients.

When calculating the dynamic impact on houses when driving piles in accordance with building regulations [2], use the formula for determining the horizontal or vertical components of soil movements (B.B. Golitsyn's formula)

$$A = A_0 (r_0 / r)^{0,5e^{-\delta(r-r_0)}} \tag{2}$$

A and A_0 - the amplitude of the horizontal or vertical component movements of the soil at distances, respectively r i r_0;

δ - vibration damping coefficient, m-1 according to data [2] according to Table 2 for hard clays and loams, it is 0,03 m^{-1};

According to [2], the damping coefficient of soil vibrations by distance is taken according to table 2 and specified according to measurement data according to regulatory documents.

On the one hand, the advantage of formula (2) is its simplicity, and on the other hand, its flexibility when approximating it using the results of observations of movement amplitudes on different sites, which are composed of different soils.

This flexibility is achieved due to the possibility of entering into it different values of A_1, including those measured at the distance r_1 and due to the substitution of different values of the damping coefficient depending on the soil conditions of the construction site.

Another technique based on the detection of dependencies between the parameters of soil surface fluctuations and its strength characteristics obtained during static sounding was presented by M. Kalyuzhniuk, V.Rud. For driving piles in sandy and clay soils, the formulas for calculating the vibration parameters differ in the values of the coefficients included in the formula

$$V = k_{\nu \max} q_s (2/r)^{tg\nu} \tag{3}$$

then the maximum vibration displacement is determined by the formula

$$A = \frac{0{,}16 \quad k_{\nu \max} q_s (2/r)^{\mathrm{tg}\nu}}{\omega} \tag{4}$$

$k_{\nu\max}$ - coefficient, which depends on the source of vibrations and the type of soil, for piles;

q_s - resistance to immersion of the probe cone during static probing, MPa;

r - the distance from the pile to the point at which the vibration parameters are determined, m;

ω - frequency of soil vibrations, Hz; $tg\,\nu$ - degree indicator, which depends on the characteristics of the upper layer of the soil with a thickness of 5-10 m.

The seismic impact of blasting is assessed using vibration velocity and vibration acceleration in comparison with the values of the MSK scale.

There are methods for determining the vibration acceleration of soil particles in the radial direction from the center of the explosion, which are based on the formula of M. Sadovskyi and differ only in coefficients included in the formula determined experimentally. They are not presented in normative literature but are used in engineering calculations.

Vibration acceleration of soil particles in the radial direction based on experimental data according to S. Medvedev [3] should be determined by the formula

$$a = 6{,}4 \cdot K_{в} \omega \sqrt{\frac{g}{\rho b_1 \tau}} \left(\frac{\sqrt[3]{C}}{R}\right)^{1{,}5} \tag{5}$$

$K_в$ - empirical coefficient, m; ρ - soil density, kg/m^3; g - acceleration of gravity, m/s^2; τ - period of soil oscillation; b_1 – speed of wave propagation, m/s (determined according to regulatory documents).

The maximum vibration acceleration of displacement of soil particles at the point of determination according to V.G. Afoninum is determined by the formula [4]

$$a = 6{,}4\omega \cdot (2{,}50 - 1{,}50)\left(\frac{\sqrt[3]{C}}{R}\right)^{2,5} \quad (6)$$

C - charge weight, kg; R - distance to the place of explosion, m; ω - frequency of oscillations, Hz (used for calculation ω =0,3 Hz).

The author of the methodology for determining the characteristics of soil oscillations gives formulas for determining the speed, which can be transformed into the given expressions for determining the vibration acceleration of soil oscillations with the help of known formulas.

To assess the intensity of vibrations during explosions, the same scale is used as during earthquakes, according to which a certain amount of vibration acceleration of vibrations corresponds to a certain point of seismicity (according to MSK). The advantages of analytical methods for calculating dynamic characteristics are ease of use, it does not require special skills and abilities from the engineer-designer.

Disadvantages are the impossibility to take into account a sufficient number of factors affecting the dynamic process by mathematical dependence. Because in order to be able to describe the phenomenon with the help of a mathematical apparatus, a certain number of assumptions are accepted.

2.2 Dynamic calculation using the finite element method

In addition to analytical methods, numerical methods for calculating dynamic characteristics, namely the finite element method, have recently been widely used to solve dynamics problems.

The choice of calculation method and specific model depends on the problem to be solved. Most of the developed software complexes are tested for certain types of foundations and soil conditions and do not allow calculations for a wide range of foundations, soil foundations, loading and deformation conditions.

Each software complex is based on a specific model of the soil environment. Evaluation and selection of a software tool must be carried out with the involvement of certain requirements that are established to solve a specific problem.

Currently, many software complexes have been created for dynamic calculations of structures, bases and foundations of buildings and structures.

Each of the programs has both its advantages and disadvantages from the point of view of solving a specific problem. For dynamic calculations, a flat and spatial resolution of the problem is adopted. The most accurate results of calculations are obtained in the case of a spatial formulation of problem solutions, but such solutions are often quite complex compared to a flat formulation. In turn, the flat problem is more universal and simple in the implementation of complex soil models, in addition, it does not require significant computing resources. If you set adequate initial data, taking into account all the features of bringing the work of the soil massif and the structure or building to a flat scheme, you can get sufficiently reliable results.

The following are among the multi-purpose software complexes: "Lira", "MSC.Nastran", "APM Dynamics", "Dinamika - 3", "NONSAP", "Selena", "SCAD", "ABAQUS", "Zenith-95" . These software complexes allow to perform both static and dynamic calculations of structures.

Software complexes suitable only for dynamic calculation of any structures are "ANSYS LS-DYNA", "LS-DYNA", "MSC/DYTRAN", "T-Flex/Dynamics".

Software complexes of a narrow profile are designed for dynamic calculations of certain types of bases and foundations. Such programs include "Dynardo", which can be used to perform a dynamic analysis of foundations (piles and slabs) compatible with the soil on the effect of wind load. "Dynamics" is a software complex for calculating port hydraulic structures, machine foundations.

The market of programs for engineering calculations offers enough of both domestic and foreign developments, which allow to perform calculations of load-bearing structures and their above-ground part with a high degree of reliability. But a less researched field is related to geotechnical engineering calculations, which are based on soil modeling processes, interactions between structures and soil. There are few high-quality and convenient programs for professionals in this field ("CONCORD", "PLAXIS").

"PLAXIS" is a universal program that is suitable for dynamic calculation of most bases and foundations, which is well adapted for calculations of this type of problems. This software complex is based on the use of the finite element method in solving dynamic problems.

The main idea of the finite element method is that any continuous quantity (vibration displacement, vibration velocity, vibration acceleration) is approximated by a discrete model, the construction of which is performed on a set of piecewise continuous functions. The essence of the finite element method is that the structure being calculated is considered to be composed of a finite number of individual elements of a simple geometric shape, tightly adjacent to each other and hinged together at the vertices of these elements. The shape and dimensions of the structure remain unchanged. The shape of the elements can be different and depends on the shape of the structure under consideration. For a flat structure, the triangular shape of the end elements is most suitable. The solid environment of the calculated structure, after dividing it into finite elements, does not lose its basic quality - it remains solid, consisting of separate two-dimensional elements.

I will consider the main points of implementation of the method of finite elements in the software complex "PLAXIS" [5].

The static equilibrium of a solid body can be formulated as

$$L^T \sigma + p = 0 \,. \tag{7}$$

In addition to the equilibrium equation, the kinematic relationship can be formulated as

$$\varepsilon = Lu \tag{8}$$

This equation goes to the 6 stress components and is collected in the vector ε as the spatial derivatives of the three displacement components are collected in the vector u using the available differential operator L. The relationship between the equations is given by the soil model. General relation

$$\dot{\sigma} = M\dot{\varepsilon} \tag{9}$$

The equilibrium equation is restated in a simplified form according to the Galerkin change principle.

$$\int \delta u^T (L^T \sigma + p) dV = 0 \cdot \tag{10}$$

In this formulation, δu represents a kinematically admissible change in displacements. Application of Green's theorem for partial integration over the first value in equation (7) leads to

$$\int \delta\varepsilon^T \sigma dV = \int \delta u^T p dV + \int \delta u^T t dS \cdot \qquad (11)$$

This is a boundary integral in which boundary displacements appear. 3 components of the limit displacement are collected in the vector t.

Equation (10) is referred to the equation of virtual work. The development of the stress state σ can be regarded as a constantly growing process

$$\sigma^i = \sigma^{i-1} + \Delta\sigma, \ \Delta\sigma = \int \dot{\sigma} dt \cdot \qquad (12)$$

σ^i represents the actual stress state;

σ^{i-1} represents the previous state of stress;

$\Delta\sigma$ - is the norm of the integrated stress over a small increment time.

If equation (11) is considered for the corresponding distance and i.

$$\int \delta\varepsilon^T \Delta\sigma dV = \int \delta u^T p^i dV + \int \delta u^T t^i dS - \int \delta\varepsilon^T \sigma^{i-1} dV \qquad (13)$$

It can be noted that the appearance of quantities in equations (7) to (13) is a function of position in three-dimensional space.

According to the finite element method, each element consists of a node number. Each node has a number of degrees of freedom, which is described by discrete values that are known within the limits of the desired value. Degrees of freedom are assigned to the displacement components. In the move field element u

$$u = N\nu \, . \qquad (14)$$

The interpolation of functions in the matrix N is often denoted by shift functions. Replacing equation (14) in the kinematic relation is given as

$$\varepsilon = LN\nu = B\nu \qquad (15)$$

In this regard, B is the interpolated stress matrix, which contains the spatial derivatives of the interpolated functions. Equation (13) can be reformulated in the described form as

$$\int (B\delta\nu)^T \Delta\sigma dV = \int (N\delta\nu)^T p^i dV + \int (N\delta\nu)^T t^i dS - \int (B\delta\nu)^T \sigma^{i-1} dV \qquad (16)$$

Discrete displacements can be placed outside the integration.

$$\delta v^T \int B^T \Delta\sigma dV = \delta v^T \int N^T p^i dV + \delta v^T \int N^T t^i dS - \delta v^T \int B^T \sigma^{i-1} dV \quad (17)$$

Якщо рівняння (2.20) містить будь-які зміни приростів δv^T, рівняння може бути записане як:

$$\int B^T \Delta\sigma dV = \int N^T p^i dV + \int N^T t^i dS - \int B^T \sigma^{i-1} dV \quad (18)$$

Equation (18) is the equilibrium condition in discretized form, the first quantity on the right together with the second quantity represents the flow of the external force vector, and the last quantity represents the internal reaction vector. The difference between the external force vector and the internal reaction vector can be balanced by the stress increment $\Delta\sigma$. The relationship between the increase in tension and the increase in compression is usually not linear. As a result of the increase in compression, they may not be directly calculated and generally require repeating operations to satisfy the equilibrium condition (18) for all points of the material.

Consider the procedure of implicit integration of differential plastic models. The stress increments $\Delta\sigma$ re obtained by integrating the normal stress according to equation (12). For differential plastic models, stress increments can generally be written as

$$\Delta\sigma = D^e(\Delta\varepsilon - \Delta\varepsilon^p) \quad (19)$$

D^e is the elasticity matrix of the material for the stress increment flow. The compression increment $\Delta\varepsilon$ is obtained from the displacement increment $\Delta\nu$ using the interpolation of the compression matrix similar to equation (14) For the elastic behavior of the material, the plastic compression displacement $\Delta\varepsilon^p = 0$. For the plastic behavior of the material, the increase in compressive stress can be written accordingly

$$\Delta\varepsilon^p = \Delta\lambda\left[,(1-\omega)\left(\frac{\partial g}{\partial\sigma}\right)^{i-1} + \varpi\left(\frac{\partial g}{\partial\sigma}\right)^i\right] \quad (20)$$

In this equation, $\Delta\lambda$ there is a displacement of the plastic multiplier and ω is a parameter that determines the type and time of integration.

For integration ϖ=1 it is called explicit and for integration it is called implicit. Vermeer showed that using implicit integration (ϖ=1) has some advantages.

In addition, it can be proven by implicit integration, under some conditions, leads to symmetry and positive differentiation of the matrix $\partial\varepsilon/\partial\sigma$ with repeated procedures has a positive effect. Because these main advantages are limited to implicit integration, they are not true for other types of time integration.

However, ω=1 equation (20) is simplified to

$$\Delta\varepsilon^{p} = \Delta\lambda(\frac{\partial g}{\partial\sigma})^{i} \quad (21)$$

Substituting equation (21) into equation (19) and successively into the equation

$$\sigma^{i} = \sigma^{tr} - \Delta\lambda D^{e}(\frac{\partial g}{\partial\sigma})^{i} c\sigma^{tr} = \sigma^{i+1} + D^{e}\Delta\varepsilon \quad (23)$$

In this regard σ^{ir} is the auxiliary stress vector related to the elastic stresses or to the test stresses, which is the new state of stress when we consider the fully elastic behavior of the material. Increase in plastic product $\Delta\lambda$, used in equation (23) can be solved from the condition that the new stress state satisfies the initial condition

$$f(\sigma^{i}) = 0 \quad (24)$$

For perfectly plastic and linearly fixed models, the increment of the plastic multiplier can be written as follows

$$\Delta\lambda = f(\sigma^{tr})/(d+h) \quad (25)$$

where
$$d = \left(\frac{\partial f}{\partial\sigma}\right)^{\sigma^{tr}} D^{e}\left(\frac{\partial g}{\partial\sigma}\right)^{i} \quad (26)$$

the symbol h stands for the steady parameter, which is 0 for perfectly plastic models and constant for linear steady models.

Replacing the ratio between stress increments and stress-compression increments $\Delta\sigma=M\Delta\varepsilon$ in the equilibrium equation leads to

$$K^{i}\Delta\nu^{i} = f_{ex}^{i} - f_{in}^{i-1} \quad (27)$$

In this equation K - stiffness matrix, $\Delta\nu$ - displacement increment vector, f_{ex} - external force vector i f_{in} - internal reaction vector. The superscript refers to the step number. The relationship between stress increment and compressive stress increment is not linear. The stiffness matrix cannot be formulated precisely in advance.

However, the general iterative procedure requires both equilibrium conditions to be satisfied. The general iterative process can be described as

$$K^j \delta v^j = f_{ex}^i - f_{in}^{j-1} \tag{28}$$

The upper symbol j refers to the integration number, δv - a vector containing displacements that gradually increase, that contribute to displacement increments with a step and:

$$\Delta v^i = \sum_{j=1}^{n} \delta v^j \tag{29}$$

n - the number of iterations in step i, the stiffness matrix K, used in equation (28) represents the behavior of the material in an approximate form. In its simplest form, K is a linear elastic solution. In this case, the stiffness matrix can be formulated

$$K = \int B^T D^e B dV \tag{30}$$

D^e - the elastic matrix of the material according to Hooke's law and B – compression stress interpolation matrix. Using an elastic-stiff matrix is a real iterative procedure until the stiffness of the material increases, even when using incoherent plastic models. To improve practical application, we have an automatic step size procedure. For material models with linear behavior in the elastic region, we use the Mohr-Coulomb model.

The processes of movement are described by the interpolation function of the elements. Within the boundaries of the displacement field element $u=(u_x, u_y)^T$ vector obtained from the discrete central value $v = (v_1 v_2 ... v_n)^T$ using the interpolation function is assembled into a matrix N

$$u = Nv \tag{31}$$

However, the interpolation function N is used to interpolate the values inside the considered element on the known values in the center. Linear elements are based on geogrid elements, planar elements and distributed loads. When the position ξ of a point (usually a stress point or an integration point) is known, one can write for the displacement component u.

$$u(\xi) = \sum_{i=1}^{u} N_i(\xi) v_i \tag{32}$$

v_I - central values;

$N_i(\xi)$ - the value of the displacement functions of the node and at the position ξ;

$u(\xi)$ - the resulting value of u at the position ξ;

n - number of element nodes.

In the program, we have movement functions for 15 nodal and 6 nodal triangular elements [5].

The basic equation of volume movement depending on time under the influence of dynamic load

$$M\ddot{u} + C\dot{u} + Ku = F \ , \qquad (33)$$

M - mass matrix; u - displacement vector; C - damping matrix; K - stiffness matrix; F - force vector.

Displacement u, velocity $\dot{u}$, acceleration can change over time.

The value $K{\cdot}u{=}F$ is rewritten as for the static deformation calculation. Matrix K contains material stiffness properties, vector F contains load components. Each element is characterized by a stiffness matrix that establishes a relationship between nodal forces and nodal displacements of the element depending on the coordinates of its nodes and the elastic properties of the material. Also, the entire design being calculated is characterized by a generalized stiffness matrix of the system, which consists of the stiffness matrices of all final elements included in its composition. We impose boundary conditions and nodal forces on this matrix. After integrating the stiffness matrix, we obtain the components of movements in all nodes of the system. In relation to stresses in the soil, the described theory is based on the linear elastic behavior of the soil. In the case of wet soil, a larger part of the soil water stiffness is added to the stiffness matrix, as in the case of static calculation. The mass matrix takes into account the mass of soil, the mass of soil water, and the mass of structures. The mass is presented as a matrix of individual load elements (soil, water, structures).

The matrix C reflects the damping of vibrations in the material. To determine the attenuation matrix, additional parameters are required that are difficult to determine from laboratory tests. Therefore, the matrix C is often described as a combination of the mass matrix and the stiffness matrix (Rayleigh damping)

$$C = \alpha_R M + \beta_R K \ . \qquad (34)$$

The boundaries of the attenuation matrix are determined by entering the Rayleigh coefficients α_R і β_R Parameter α_R determines the effect of mass on the damping of the system. When the proportion of the mass matrix M in the damping matrix C increases (for example α_R=10^{-2} and β_R=10^{-3}) damping of lower vibration frequencies occurs, and when the share of the stiffness matrix K in the damping matrix C increases (for example α_R=10^{-3} і β_R=10^{-2}) higher frequencies of oscillations are attenuated. With the standard installation of the program, the attenuation of the Relay is not taken into account α_R=β_R= 0.

При динамічних розрахунках форма інтегрування по часу визначається фактором стабільності і точності процесу розрахунку. В схемі розрахунку використовується метод неявного інтегрування по часу. В цьому методі переміщення і швидкість для точки в часі $t+\Delta t$ записуються відповідно:

In dynamic calculations, the form of integration over time is determined by the factor of stability and accuracy of the calculation process. The calculation scheme uses the method of implicit integration over time. In this method, displacement and velocity for a point in time $t+\Delta t$ are written respectively

$$\begin{aligned} \ddot{u}^{t+\Delta t} &= c_0 \Delta u - c_2 \dot{u}^t - c_3 \ddot{u}^t, \\ \dot{u}^{t+\Delta t} &= c_1 \Delta u - c_4 \dot{u}^t - c_5 \ddot{u}^t, \\ u^{t+\Delta t} &= u^t + \Delta u. \end{aligned} \tag{35}$$

Δt – time step Coefficients $c_0 ... c_5$ can be expressed in a time step and in the integration of parameters α *і* β. Coefficients α *і* β are determined by the numerical precision of the integration time and are not equal α *і* β for Rayleigh damping. In order to obtain a stable result, the following condition must be applied: $\beta \geq 0,5$; $\alpha \leq 0,25(0,5+\beta)^2$. Standard values of coefficients can be used in many calculations α=0,25, β=0,5.

With this method of movement, the speed and acceleration at the end of the time step are expressed through the values at the beginning of the time step and the increment of the movement. With implicit integration, equation (33) must contain the time at the end of the step $t+\Delta t$

$$M\ddot{u}^{t+\Delta t} + C\dot{u}^{t+\Delta t} + Ku^{t+\Delta t} = F^{t+\Delta t}, \quad (36)$$

This equation is combined with expression (36) for displacements, velocity and acceleration at the end of the time step

$$(c_0 M + c_1 C + K)\Delta u = F_{ext}^{t+\Delta t} + M(c_2 \dot{u}^t + c_3 \ddot{u}^t) + C(c_4 \dot{u}^t + c_5 \ddot{u}^t) - F_{\text{int}}^t, \quad (37)$$

In this form, the system of equations for dynamic analyzes is also used for static calculations. The difference will be in the stiffness matrix, which contains additional values for mass and damping, and the values of *c*. The right side of the equation contains additional values for determining the speed, acceleration at the beginning of the time step (time Δt).

Despite the implicit integration, the time step used in the calculations is limited. If the time step is very large, then as a result of calculations we will have deviations and the result will lose accuracy. The critical time step depends on the maximum frequency of the model and the accuracy of the connection of the finite elements. For a single element we will have

$$\Delta t_{crit} = \frac{B}{\alpha\sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}}\sqrt{1+\frac{B^4}{4S^2}-\frac{B^4}{4S}[1+\frac{1-2\nu}{4}\frac{2S}{B^2}]}}, \quad (39)$$

The value of the first root is the speed of the compression wave. The factor α depends on the type of element.

For a 6-node element $\alpha = 1/(6\sqrt{c_6})$, де $c_6 \approx 5{,}1282$, for a 15-node element $\alpha = 1/\sqrt{19c_{15}}$, де $c_{15} \approx 4{,}9479$.

Δt Another significant factor is Poisson's ratio, the average number of the length of the element *B*. The surface *S* is used to describe the average number of the length of the element. In the final model of the element, the critical time step is equal to the minimum value Δt for all elements according to (39). The chosen time step is so small that the wave in a unit step moves a smaller distance than a unit element.

In the case of static strain analyses, the described limit displacements are represented at the boundaries of the element model. For dynamic calculations, the boundaries will be further away than for calculations of static deformations, because rapid dispersion of oscillations occurs. When the boundaries are very close to the dynamically loaded structure, the oscillations quickly reach them and the oscillations are reflected and propagated in the opposite direction. This leads to distortion of calculation results. However, placing the boundaries away from the object requires many additional elements and therefore a lot of additional memory and time.

To prevent these negative consequences, absorption limits are applied. Absorption limits were used in the calculation of dynamic characteristics and subsidence. The components of normal stress and shear stress are absorbed in the direction of the coordinate axes of the calculation scheme. They are described by certain expressions consisting of the product of dynamic characteristics, soil density, transverse and longitudinal wave velocities and absorption coefficients. That is, longitudinal waves are completely attenuated, the attenuation coefficient C_1=1, and the transverse ones are attenuated only 25%, C_2=0,25.

These methods have their advantages and disadvantages, and relate to specific research problems in this field. When choosing absorption boundaries, a humidifier was used instead of using fixed boundaries in the main direction. The dampener ensures that the voltage increase at the boundary is absorbed without impact.

With the help of "PLAXIS" software complexes, the effects of soil vibrations and structures can be fully analyzed on the basis of solving the axes of a symmetric and planar problem. They include the final set of a package of modules for analyzes of deformations and stability of geotechnical projects. The dynamic model includes the inertia of the base layer and the load action time. Oscillations weaken with increasing distance from the source of oscillation due to effects similar to geometric damping. When performing calculations, "PLAXIS" can be started in the mode of automatic selection of the value step and the time step. This allows you to avoid choosing the appropriate load increment for plasticity calculations, which guarantees the efficiency and accuracy of the calculation process.

2.3 Required output data for dynamic calculations

1. Data on structures and loads.

The composition of the initial data for the design of the foundations of machines with dynamic loads according to [7] clause 1.1 should include: technical characteristics of the machine (name, type, number of revolutions per minute, total mass, mass of moving parts, speed of falling parts); data on the value, place of application and directions of action of static and dynamic loads in normal operation, dimensions of load transfer platforms, information on the presence of factory vibration isolation in machines with an indication of dynamic loads transmitted to the foundations taking into account this vibration isolation; data on the limit values of deformations of foundations and their bases (settlement, roll, deflection of the foundation and its elements, amplitude of oscillations), if such limitations are caused by the conditions of production technology, machine operation; data on the conditions of placing the machine (equipment) on the foundations: separate foundations for each machine (aggregate) or their group installation on a common foundation, data on the characteristics of the equipment support plates, data on the type of their connection to the foundation, etc.

When studying soil vibrations due to pile driving, the initial data should be: data on the geometric dimensions of the piles, on the method of their immersion, technical characteristics of the equipment with the help of which the pile immersion process is carried out.

When assessing the impact of blasting, it is necessary to have data on the specifics of blasting and explosives.

2. Data about surrounding objects.

When designing, it is necessary to pay attention to nearby structures and equipment when designing foundations for machines, and buildings and structures when conducting pile-dive and blasting works.

When designing, it is necessary to take into account the presence of high-precision and vibration-sensitive equipment, the condition of buildings and structures located nearby, their structural features, and depending on this, draw conclusions about the permissible amplitude of oscillations.

3. Data on the engineering and geological conditions of the construction site and the physical and mechanical properties of the foundation soils.

For the calculation of foundations according to building regulations, the main characteristic of the soil used in the calculations is the modulus of elasticity of the soil, which is used to calculate the coefficients that take into account the properties of the soil. When calculating the vibration impact from the sinking of piles and from blasting works using the analytical method, engineering geological conditions are taken into account with coefficients that are determined depending on the soil category. Soil density is taken into account.

When using numerical methods of entering the geometry of the soil layers, structure, loads and boundary conditions, it is based on CAD drawing procedures, which provide a detailed and accurate simulation of the real situation. The engineering and geological conditions of the site are taken into account on the basis of such physical and mechanical characteristics of the soil as: soil specific gravity, adhesion, angle of internal friction, modulus of deformation, Poisson's ratio. To enter the geometry in "PLAXIS", such elements as a beam, a hinge, contact surfaces, anchors, geotextiles (geogrids), tunnels, boundary conditions, loads are presented. When performing geotechnical calculations, it is necessary to have basic soil models to simulate nonlinear and non-stationary behavior of soils. At the same time, it is necessary to take into account the soil substrate itself, hydrostatic and non-hydrostatic pore pressure in it. Thus, the main emphasis is placed on the interaction of the soil and those structures that can be erected on this site. In the absence of any category of initial data, it is impossible to carry out further calculations using analytical or numerical methods.

2.4 Peculiarities of drawing up calculation schemes

For calculating the dynamic characteristics and settlement of the foundation, the compiled calculation scheme is important. Calculation schemes compiled for calculation have their own characteristics.

When calculating the dynamic characteristics of the foundation for the equipment using the analytical method, the following is accepted

1. The machine-foundation system has 6 degrees of freedom: 3 displacements and 3 rotations, which can be replaced by research with an equivalent, specially selected system with one degree of freedom (for vertical or horizontal oscillations) or with two degrees of freedom (vertical or horizontal oscillations taking into account rotational or rotational components of vibrations).

1. The coordinate system is chosen to pass through the common center of gravity of the machine and the foundation. All acting

forces, moments, displacements act on some point of the foundation relative to these axes. It is assumed that the system has 2 vertical planes of symmetry and the horizontal axes lie in those planes. These axes are the main axes of the body, relative to which the inertia forces are zero.

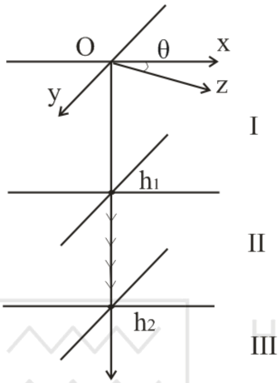

Fig 2. Calculation scheme for calculation of soil vibrations during pile immersion by impact method

2. In the case of elastic non-uniform compression (rotation of the foundation sole relative to the horizontal axis passing through the center of gravity of the foundation sole perpendicular to the plane of oscillations), it is permissible to assume that the plane of oscillations is parallel to the line of action of the acting force or the plane of action of the disturbing moment.

3. However, there are no instructions in the construction regulations to take into account the deepening and backfilling, but the instructions [8] state that for a more accurate assessment of the stiffness coefficients of the base, the influence of the lateral backfilling of the foundation on the increase of these coefficients should be taken into account, conducting special studies for this purpose.

When calculating soil vibrations from driving piles, when choosing a mathematical model of a pile as a source of vibrations, it is considered as an axis of a symmetrical source. Wavelengths propagated in the soil during pile driving are much larger than its transverse dimensions, so although the pile is a volume source, it can be replaced by the line of action of forces. Plastic deformations in the region in the immediate vicinity of the pile are neglected and the problem is treated as elastic. That is, we have a perfectly elastic homogeneous half-space and a linear axis symmetric pulse source of oscillations in the half-space . We have a uniform nature of load distribution along the line of action of the force (Fig. 2.4). 1st, 2nd, and 3rd regions in the half-space, conventionally separated by planes $z=h_1$, $z=h_2$.

Seismic phenomena during an explosion are a small model of a natural earthquake. The source of seismic energy during an explosion is the explosive charge. That is, the explosion phenomenon can be represented as the loading of an elastic half-space by a concentrated force, which reveals the main regularities of the formation and propagation of seismic vibrations (Fig. 3).

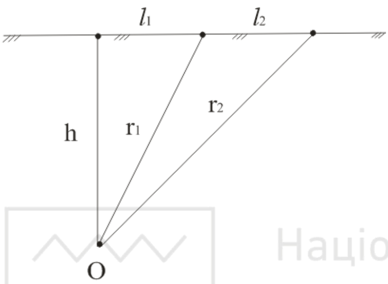

Fig 3. Calculation scheme for calculating soil vibrations from explosions during rock development

The calculation scheme used in calculating the dynamic characteristics of equipment foundations, soil vibrations and subsidence due to dynamic influence using the finite element method has the following features:

1. When drawing up the calculation scheme, ties and absorption boundaries are superimposed on the side and bottom boundaries. Elms prohibit the movement of the side borders along the abscissa axis, and the lower border along the ordinate and abscissa axes.

2. Dynamic studies in "PLAXIS" software complexes can be divided into analyzes of two types of problems:

- problems with a single source of oscillations (oscillations of machine foundations, soil oscillations during pile driving);

- problems of earthquakes. Earthquakes can be modeled by describing movements with a dominant horizontal component.

During an earthquake, the dynamic load acts on the entire plane of the bottom of the model.

3. From the created geometric model, the program automatically generates an unstructured ordinary mesh with the possibility of global and local changes in its density. The use of high-order elements in the model is useful for the uniform distribution of stresses in the soil and the accurate prediction of unacceptable loads. The user is given a choice between 6-node and 15-node elements, which can be successfully used in calculations.

4. The program takes into account advanced models in geotechnics for nonlinear modeling of soil behavior that does not depend on time.

5. To perform calculations, in addition to establishing the basic physical and mechanical characteristics of soil and material (modulus of deformation, specific adhesion, angle of internal friction, specific weight, Poisson's ratio), it is possible to set properties from the point of view of permeability, taking into account filtration. It is possible to use dried and not dried soil in calculations. These conditions are related to the ability of pore water to move between soil particles, which can lead to a change in volume and is accompanied by an excess of additional pore water pressure. When using the Mohr-Coulomb model, it is necessary to enter the values of physical and mechanical characteristics of dry soil during calculations.

Usually, the calculation schemes made by analytical and numerical methods are quite different, but they have common assumptions, for example, in the geotechnical analysis of a certain structure or building (foundation for equipment, pile), they are taken as made of linear-elastic, rigid material, and such that there is no porosity.

2.5 Soil base models used in calculations

Conducting a dynamic calculation using analytical and numerical methods is based on the choice of a soil base model, which in a certain way depends on the accuracy of the obtained result.

In the dynamic calculation of foundations under machines using the analytical method, the base is considered as an elastic-viscous linearly deformed medium. The properties of the environment in the calculation are determined by the coefficients of elastic uniform and non-uniform compression, elastic uniform and non-uniform shear and coefficients characterizing damping.

When calculating soil vibrations from pile driving and from explosions, an elastic half-space is used as a soil model. To simplify the solution of the problem, it is assumed that the material of the half-space is perfectly elastic, homogeneous and isotropic, and the relationship between deformations and stresses is linear. In general, all assumptions, with the exception of soil homogeneity, are sufficiently consistent with experimental data during pile driving. Indeed, as a result of the small amplitudes of displacements that occur when driving piles in the first approximation, it can be assumed that the absorption of vibration energy by the soil does not occur. Soil is a perfectly elastic material. For the same reason, the geometric and physical non-linearity of the dependence of soil deformation on stresses can be disregarded. The assumption of soil homogeneity made to explain the general patterns of wave propagation in soils. But the further away from the place of the explosion, the more significant is the influence of the environment and its composition. This is explained by the fact that the medium (soil) differs significantly in its properties from the elastic half-space. Recently, there have been attempts by scientists to improve soil models when describing dynamic phenomena with analytical expressions, but no additions to building regulations have been made.

The development of numerical methods makes it possible to bring the model of the soil environment closer to the real one when calculating dynamic phenomena. When modeling the dynamic processes of foundations and foundations, a static calculation was first performed. After the static calculation, the dynamic behavior of foundations and foundations was modeled. During the static calculation, discrete models were used to simulate the non-linear, rheological behavior of soils. The Mohr-Coulomb nonlinear model is based on soil parameters that are known in most cases.

This phenomenological model of soil deformation involves taking into account physical and geometric nonlinearity, dilatancy, compaction in the process of deformation, pore and hydrostatic pressure, shrinkage and swelling of the soil.

The Mohr-Coulomb elastic-plastic model is based on 5 input parameters: modulus of elasticity and Poisson's ratio as for elastic soil, angle φ and specific adhesion as for plastic soil and ψ- angle of dilatancy (spreading). General deformations include linear (elastic) and plastic parts, and the plastic component of deformations occurs after the stress state reaches the limit of proportionality (yield, strength).

The relationship between stresses and strains is bilinear, Fig. 4.

For the limit of proportionality at the point (elementary volume) of the array, for the condition of plane deformation, the Mohr-Coulomb equation is used in the form:

$$\frac{\sigma_1-\sigma_2}{2}+\frac{(\sigma_1+\sigma_2)\sin\varphi}{2}-c\cos\varphi=0$$

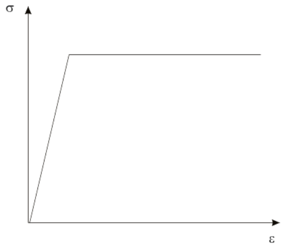

Fig 4. Graph of dependence between stresses and deformations of an elastic-plastic medium

Plasticity is associated with the development of irreversible deformations. In order to estimate the amount of plasticity in the calculations, the stretching (stress) function is introduced. The stretch (stress) function can often be represented as a surface in the principal stress space.

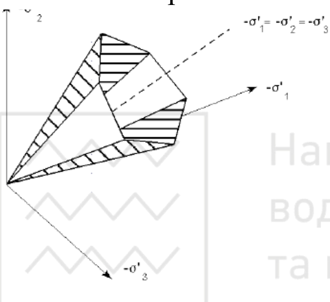

Fig. 5. The cone of principal stresses e space of the Mohr-Coulomb model

A perfectly plastic model is based on a model with a constant stretching surface, that is, the stretching surface is completely determined by the model parameters and is not subject to plastic deformations. The Mohr-Coulomb condition is an application of the law of friction

Coulomb to general stress states. In fact, this condition guarantees that Coulomb's law of friction holds in any plane within the material element.

The complete Mohr-Coulomb stretch condition can be defined by three stretch (stress) functions when the principal stress conditions are formulated

$$\begin{aligned}
f_1&=\frac{1}{2}(\sigma_2'-\sigma_3')+\frac{1}{2}(\sigma_2'+\sigma_3')\sin\varphi-c\cos\varphi\le 0,\\
f_2&=\frac{1}{2}(\sigma_3'-\sigma_1')+\frac{1}{2}(\sigma_3'+\sigma_1')\sin\varphi-c\cos\varphi\le 0,\\
f_3&=\frac{1}{2}(\sigma_1'-\sigma_2')+\frac{1}{2}(\sigma_1'+\sigma_2')\sin\varphi-c\cos\le 0.
\end{aligned}\tag{41}$$

Two parameters of the plastic model appear in the stretching functions - the friction angle φ and the adhesion *c*. These functions together represent a hexagonal cone of principal stresses in space, as shown in Fig. 2.7.

When the Mohr-Coulomb model is applied to general stress states, a special treatment is required for the intersection of the two stress surfaces. Some programs use a smooth transition from one stress surface to another, that is, by rounding the corners. In "PLAXIS", however, the exact form of the full Mohr Coulomb model is implemented, using a sharp transition from one stress surface to another.

When c>0, the stress state is determined by the standard Mohr-Coulomb criterion. In fact, the allowable tensile stresses increase with coupling. This behavior can be analyzed by "PLAXIS" by determining another solution of the stress state. In this case, Mohr circles with negative head pressure cannot be. Another stress state method introduces an additional three reduced functions, which are defined as

$$\begin{aligned} f_4 &= \sigma_1' - \sigma_1 \le 0 \\ f_5 &= \sigma_2' - \sigma_1 \le 0 \\ f_5 &= \sigma_3' - \sigma_1 \le 0 \end{aligned} \tag{42}$$

When this stress state procedure is used, the allowable stress, the bound strain function, σ is assumed to be zero. The flow rules are followed for the three stresses. For the stress state within the reduced surface, the elastic behavior obeys Hooke's law for an isotropic linear elastic medium.

The basic principle of elastic plasticity is that deformations and stresses have elastic and plastic parts $\bar{\varepsilon} = \bar{\varepsilon}^e + \bar{\varepsilon}^p$,

$$\dot{\bar{\varepsilon}} = \dot{\bar{\varepsilon}}^e + \dot{\bar{\varepsilon}}^p, \tag{43}$$

Hooke's law for the relationship between stresses and elastic strains

$$\dot{\bar{\sigma}}' = \overline{\overline{D}}^e \dot{\bar{\varepsilon}}^e = \overline{\overline{D}}^e (\dot{\bar{\varepsilon}} - \dot{\bar{\varepsilon}}^p), \tag{44}$$

In the general case, plastic deformations will be written as:

$$\dot{\bar{\varepsilon}}^p = \lambda \frac{\partial g}{\partial \bar{\sigma}'}, \tag{45}$$

$\dot{\bar{\varepsilon}}^p$ - plasticity parameter. For exclusively elastic behavior, the parameter is zero, while in the case of plastic behavior it is positive

$\lambda = 0$ for f<0 *or* $\frac{\partial f^T}{\partial \bar{\sigma}'} \bar{\bar{D}}^e \dot{\bar{\varepsilon}} \le 0$, elasticity;

λ>0 *for f*=0 *and* $\frac{\partial f^T}{\partial \bar{\sigma}'} \bar{\bar{D}}^e \dot{\bar{\varepsilon}} \rangle 0$, plasticity

These equations may be used to derive the following relationship between effective stresses and stresses for an elastoplastic problem

$$\dot{\bar{\sigma}}' = (\bar{\bar{D}}^e - \frac{\alpha}{d} \bar{\bar{D}}^e \frac{\partial g}{\partial \bar{\sigma}'} \frac{\partial f^T}{\partial \bar{\sigma}'} \bar{\bar{D}}^e) \dot{\bar{\varepsilon}}, \quad (46)$$

$$d = \frac{\partial f^T}{\partial \bar{\sigma}'} \bar{\bar{D}}^e \frac{\partial g}{\partial \bar{\sigma}'}, \quad (47)$$

If the behavior of the material is elastic, then the value of α is zero. If the material behaves plastically, then this value is equal to 1. The theory of plasticity mentioned above is limited to the stretching surface and does not cover the entire surface of the reduced contour presented in the Mohr-Coulomb model. For such a surface, the theory of plasticity was extended others, with two or more plastic potential functions

$$\dot{\bar{\varepsilon}}^p = \lambda_1 \frac{\partial g_1}{\partial \bar{\sigma}'} + \lambda_2 \frac{\partial g_2}{\partial \bar{\sigma}'} + \ldots \quad (48)$$

The Mohr-Coulomb nonlinear model makes it possible to more accurately describe the behavior of the soil under loads, but due to the complexity of the mathematical apparatus, it is used only in the calculation of buildings and structures using a computer. For the analytical description of dynamic phenomena, the elastic half-space model is sufficient and allows solving engineering problems with satisfactory accuracy.

When calculating according to the software complex, it is possible to use other soil base models. The loose soil model is used to accurately analyze the logarithmic work in compression of normally consolidated loose soil. The soft creeping soil model is an improved version of the soft soil model that includes simulation of the second stage of creep. The solid model is used for harder soils - such as overconsolidated clays and sands. An elastic-plastic type of hyperbolic model is used here [8,9,11].

The reinforced soil model is a model for modeling the behavior of different types of soil (both soft and hard). When under the action of a variable load on the soil, the stiffness decreases, and at the same time, irreversible plastic deformations develop. This model uses the theory of plasticity, takes into account dilatancy, and stretching of the upper part of the hyperbola.

The main characteristics of the model [10]:

- load depending on soil stiffness *m*;
- shear stiffness in the standard drained triaxial test E_{50}^{ref} ;
- tangent stiffness for initial compression load E_{oed}^{ref} ;
- elastic unloading E_{ur}^{ref} ;
- parameters: c - specific adhesion, φ - angle of internal friction, ψ - angle of dilatation.

The main feature of this model is the dependence of stresses on stiffness.

Assume that the triaxial load application conditions, $\sigma_{2'}=\sigma_{3'}$ and $\sigma_{1'}$ are the main compressive stresses.

The model explains both plastic and elastic deformations. Plastic deformations develop only when the initial load is applied, and elastic deformations develop both during the initial load and during unloading - reloading. For dried triaxial stress tests $\sigma_{2'}=\sigma_{3'}$=constant [5].

2.6 Principles of calculations

Determination of the dynamic characteristics of the foundation of the machine, structure, soil is based on the definition of a dynamic equation that can be determined according to the D'Alembert principle (kinetostatics). At the same time, the sum of the acting forces and the forces of inertia is zero, or is based on Newton's second law - the law of dynamics (Fig. 6).

The obtained dynamics equation can be solved by mathematical methods. Mathematical expressions for finding dynamic characteristics of machine foundations and soil are presented in building regulations or in scientific literature. The dynamics equation can be solved by numerical methods, namely the finite element method implemented in the "PLAXIS" software complex.

When calculating the foundation of the machine using mathematical expressions of dynamic characteristics, the following must be taken into account:

- the eccentricity in the distribution of foundation masses is not taken into account, if it does not exceed 3-5% according to clause 1.8 [7];
- when several disturbing forces are acting on the foundation of the machine at the same time and there is no data on their phase relationship, variants of in-phase and anti-phase action of forces are considered, which causes the most unfavorable forms of oscillations;
- when calculating to take into account the properties of the material and soil, the deformation modulus and coefficients are used.

The process of calculating dynamic characteristics using the finite element method in "PLAXIS" is also divided into phases. In each of the phases of the calculation, a specific load is activated at a certain time of the simulation. When performing a dynamic calculation, we have the following phases:

Phase 1 - applying a static load to the base from the own weight of the structure or foundation.

Phase 2 - application of a static load acting on the structure or foundation. If there is no such load, such as when calculating the dynamic characteristics of a tailings dam, this phase is not included in the calculation.

When performing calculations in phase 1 and 2, it is possible to specify a new state that should be obtained at the end of the calculation phase. And the geometric scheme and load can also be changed.

Phase 3 - applying a dynamic load. We set the dynamic load and the frequency with which it is applied.

Phase 4 - vibration damping, when there is no dynamic load.

Each phase of the calculation is generally divided into a number of steps. The presence of steps is explained by the non-linear behavior of the soil, which requires loads that are applied in small parts (step by step).

The value of the quantity calculated in the previous steps of the calculation can be ignored at the beginning of the current phase of the calculation. In this way, the beginning of the calculation is carried out from the zero field. If this function is not selected, then step values calculated in the current phase of the calculation process will be added to those calculated in the previous phase.

Each phase in the calculation has a specific time interval. The program can work in the mode of automatic selection of size increment or time step. The calculation end time is calculated automatically by adding time intervals to all successive phases.

The calculation step used in the dynamic calculation is constant and is equal to $\delta t = \Delta t / (n \cdot m)$: where Δt is the duration of the dynamic load (time interval), n is the number of additional steps and m is the number of dynamic substeps. For each additional step (from 1 to 250, set in the program 100), the program calculates the number of substeps needed to reach the end time and evaluates δt_{crit}. If the calculation scheme contains very small elements, then the number of substeps can be large, which will lead to a decrease in the accuracy of calculations. Then you need to change the number of substeps.

During calculations, it is possible to constantly adjust the grid of finite elements in the calculation process. In some cases, the usual calculation of small deformations can show a significant change in the mesh geometry. In this case, it is advisable to perform the calculation on a variable grid.

"PLAXIS" has advanced capabilities for graphical presentation of calculation results. The exact values of the calculated value are entered in the output tables. All data can be output to a printer or plotter in tabular or full-color format. Graphic output of the deformed mesh, general or discrete vibration displacements, vibration velocities, vibration acceleration is carried out. "PLAXIS" allows you to create graphs of all dynamic characteristics at any point of the calculation scheme [5].

3. Conclusions

1. The application of the mathematical and numerical method of finite elements in dynamic calculations of structures, buildings, and soil allows to solve the following problems with a certain accuracy: to determine the vibration displacement, vibration acceleration, vibration speed of structures, soil; to find the amount of dynamic settlement of foundations depending on certain soil conditions.

2. The use of a mathematical method in dynamic calculations allows to describe mathematically with the use of certain assumptions and to determine the dynamic characteristics of the object's oscillations and the settlement of the foundation, which is investigated using formulas. And the software complex using the

numerical method of finite elements makes it possible to obtain a complete picture of the field of vibration displacements, vibration accelerations, vibration velocities by obtaining graphs of the dependence of dynamic characteristics at any point of the calculation scheme on time, graphical output of the deformed grid.

3. When calculating dynamic characteristics using the analytical method, an elastic model of the soil environment is used. And when calculating according to the finite element method, a static calculation was first performed, where the basis is considered physically and geometrically nonlinear, taking into account dilatancy, etc. Then a dynamic calculation was carried out, where the behavior of the base was assumed to be elastic.

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REGARDING THE ISSUE OF POST-WAR DEVELOPMENT OF MINING REGIONS AND RESTORATION OF DESTROYED INFRASTRUCTURE FACILITIES

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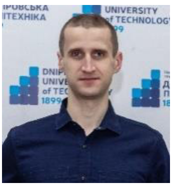

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Abstract

The subject of the study is the patterns of interaction and distribution of forces between reinforcement elements as fibers of a composite structure of regular structure, as well as hydrogeodynamic, energy and geometric parameters of disturbed soil massifs during the restoration of destroyed infrastructure facilities.

The purpose of the work is to simplify and speed up the commissioning of bridge structures with span structures destroyed as a result of military operations based on the scientific justification of a single complex technology for their rapid restoration using composite cable ropes of domestic production.

As an alternative to the complete restoration of destroyed bridges, it is proposed to use cable-stayed structures in whole or in part. As bridge cables, it is proposed to use well-known rubber composite ropes, the production of which has been established in Ukraine. The reliability of the proposed ropes can be increased by increasing the number of ropes in them.

A model and algorithm for calculating the stress-deformed state of a rubber cable rope of an arbitrary design has been developed, taking into account the nonlinear deformation of the cables and the presence of a discontinuity of an arbitrarily located cable. The model was built using the methods of mechanics of composite materials. It is solved analytically in a closed form.

Key words: post-war infrastructure restoration, cable-stayed bridges, rubber-cable ropes, composite materials, tower excavator.

Introduction

An important component of sustainable economic development, especially in mining regions, is a developed infrastructure, in particular a transport network. Both products for sale and equipment and materials for production needs are delivered by roads, tunnels and bridges. Serious damage to the transport infrastructure leads to disruption of supplies. This becomes the cause of production downtime, due to which the enterprise bears colossal losses [1–3].

According to Ukravtodor, more than 150 bridges and overpasses were destroyed because of the war in Ukraine, including in Chernihiv region – 27. In Kharkiv region – 25, in Kyiv region – 24. Traffic has already been restored on 76 bridges. This means that detours or temporary crossings have been built near the destroyed buildings. According to the latest estimates, it will take about 4 years to rebuild the entire destroyed infrastructure of Ukraine. [4]

Bridge crossings are the most important component of the country's logistics system. The main form of their destruction during military operations is the damage to the fabric and the destruction of overhead structures. The restoration of destroyed bridges is the most important and primary task of the state policy to ensure the independence and national security of Ukraine.

In addition, a very important issue is the search for domestically produced materials for the restoration of bridges. This will contribute to the reduction of costs for the post-war reconstruction of Ukraine, and at the same time stimulate the development of its own industry, in particular mining, construction and machine-building.

Analysis of bridge destructions in Ukraine.

After the de-occupation of its territories, the critical infrastructure is being gradually restored in Ukraine. For this, damaged roads and destroyed bridges are being restored as a priority. It is easiest and fastest to restore transport connections through the channels of small rivers.

One of the ways to build a crossing across a small river is to lay rigid polypropylene pipes of large diameter on the bottom of the river along the direction of its flow (fig. 1). The top is densely covered with screening, asphalt is laid. The banks of the river are strengthened by rock mining mass of a large fraction.

Such a crossing provides the passage of small cars, pedestrian connection of the shores. Moreover, the constructed crossing does not impede the flow of the river. However, such a solution is temporary, and later this crossing will collapse under the influence of precipitation and groundwater. Intensive movement of such a crossing, especially heavy-duty vehicles, is impossible.

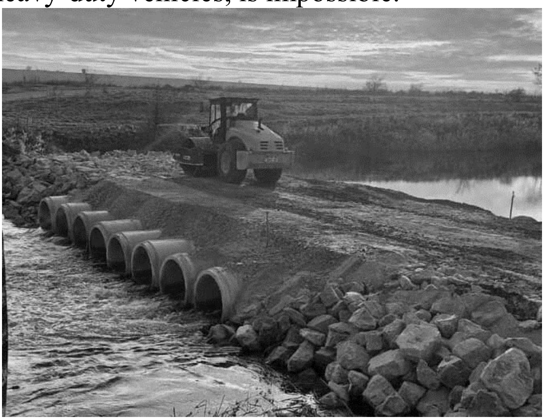

Fig. 1. Construction of a crossing over the Ingulets River connecting the village of Zarichne with Arkhangelsky of the Visokopil community [5]

There is also a solution that involves the rapid construction of a full-fledged bridge. For this purpose, a detour of the destroyed bridge with a descent along the river bank is being built (fig. 2). The created detour is connected by a bridge with smaller supports and a flight, as it is located below the destroyed bridge, closer to the bottom of the river.

It is obvious that such a decision is temporary, because there is a threat of rising water level, as a result of which the bridge may be flooded. In addition, such a detour is the cause of a dangerous traffic factor, namely, limited visibility due to the shape of the detour route and the presence of a destroyed bridge.

Fig. 2. Temporary bridge across the Siverskyi Donets River (Izyum, Kharkiv Region) [6]

The cases described above are the most frequent. For them, it is possible to find a quick temporary solution. However, there is also the problem of broken long bridges across wide rivers. In the vast majority of such bridges, one or more spans were destroyed and supports near one of the banks of the river were damaged (fig. 3). While part of the bridge on the opposite bank is almost undamaged.

Such destruction, as a rule, is the result of blowing up the bridge before the retreat of the army that previously controlled it. The destruction of the spans of the long bridge requires a complete reconstruction of the destroyed part of it. The temporary measures described above do not work in this case.

Fig. 3. The destroyed bridge over the Dnipro River.
Frame from the movie “RIK” (“The Year”, 2023) [7]

There are cases when the bridge is completely destroyed. At the same time, the river is not very wide, but it is not narrow enough to build a temporary bridge, as shown in the photo (fig. 2) or crossing (fig. 1). In the Kherson region, the Daryiv Bridge (fig. 4) across the Ingulets River can be restored in 1-3 months. These works will cost an average of 60-80 million hryvnias.

Fig. 4. The destroyed Darivskyi road bridge across
the Ingulets River (Kherson Region) [8]

The destruction of very long bridges, such as the Antonivsky bridge, is possible when the central spans are destroyed (fig. 5). At the same time, the elimination of such damage is complicated by the intensity of the river flow in the place of destruction.

Fig. 5. The ruined Antoniv bridge across the Dnipro River
Frame from the movie "RIK" ("The Year", 2023) [9]

An analysis of the destruction of bridges caused by hostilities in Ukraine showed that the vast majority of damaged objects are small bridges, the restoration of which does not take much time. In addition, temporary measures are being implemented that allow us to restore transport connections in critical sections by our own efforts. Temporary crossings and bridges are located below the destroyed ones, due to which there is a threat of their flooding.

There are no temporary solutions for the rehabilitation of large bridges. For their restoration, it is necessary to attract a significant amount of funds, including international aid. However, such bridges do not collapse completely. Therefore, the not destroyed part can be used in the restoration of the bridge.

While for small bridges, a temporary solution is to build a crossing below the destroyed bridge, for large bridges, such a solution can be the construction of the destroyed sections of the pylon of the cable-stayed bridge. Since the construction of such bridges requires imported components, and there are a lot of destroyed objects, it is necessary to rely on the use of alternative materials of domestic production.

Schemes of cable-stayed bridges.

Cable-stayed bridges are called bridges, the main elements of span structures of which are inclined rectilinear cables that suspend stiffening beams from pylons (fig. 6).

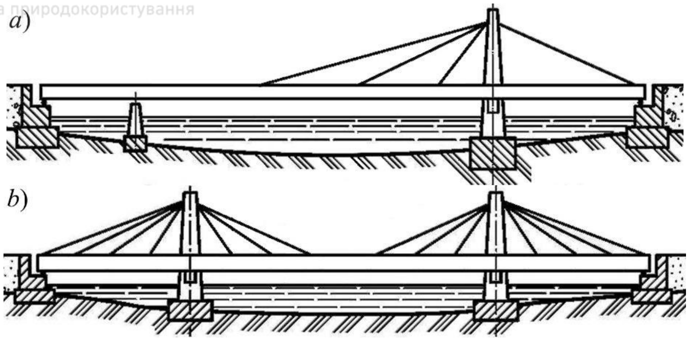

Fig. 6. Cable-stayed bridges with one (*a*) and two (*b*) pylons

Inclined cables are attached to the pylons and support the stiffness beam, being elastic supports for it. A special role is played by the outer cables connecting the top of the pylon with a fixed point. They prevent the horizontal movement of the top of the pylon under the action of temporary loads and provide the system with great rigidity in the vertical plane. The cables work only in tension, the pylons - mainly in compression, the stiffening beam - in bending and on the effect of horizontal forces, which are in the cables. The stiffening beam is supported by cables in many places and works as if on an elastic basis, it does not have significant bending moments, so it can have a small height. It can rest on pylons, in which case significant negative moments arise in the area of what is being supported. To avoid them, recently they began to abandon the fact that it rests on the pylons, transferring the weight of the stiffness beam and the temporary load to the pylons only through the cables.

Cable-stayed bridges with reinforced concrete stiffening beams and pylons began to be used recently. The first of them was built in Venezuela across the lake. Maracaibo in 1962, the second - across the harbor of the Dnipro River in Kyiv in 1963 (Fishing cable-stayed bridge). To date, there are more than 80 cable-stayed reinforced concrete bridges in the world, but they have significant prospects for development. They make it possible to cover spans of more than 1000 m. They are usually erected at the intersection of deep rivers, sea bays or straits, at the mouth of rivers, where the construction of supports is difficult. By 1986, in reinforced concrete cable-stayed bridges, a record span of 440 m will be achieved in a bridge built in

1983 in Spain (bridge Los Barrios de Luna). In 2024, the longest cable-stayed bridge will be Changtai Yangtze River Bridge, 1,176 m long in Jiangsu, China.

Three cable-stayed bridges have now been opened in Ukraine: two in Kyiv (South and North), one in Zaporizhzhia New bridge across the Dnipro. The above-mentioned Rybalsky cable-stayed bridge was decommissioned in 2009. 1256 m length South bridge opened in 1990, 816 m length North bridge opened in 1976, 660 m length New bridge in Zaporizhzhia across the Dnipro opened in 2022. At the beginning of 2022, under the President's program "Big construction", the construction of the New Kremenchug bridge over Dnipro Two reinforced concrete pylons with a total height of 115 m were built. A concrete plant with a capacity of 160 m^3/h was built for construction needs. [10]. This indicates the rapid development of the bridge construction industry in Ukraine.

The schemes of cable-stayed bridges are distinguished depending on the number of pylons, the system, and the number of planes of cables. With one pylon (Fig. 6*a*), the cables are located asymmetrically relative to it, they are attached to the stiffness beam in the main span at different angles. This requires different structural solutions of their fastening nodes, and the presence of small attachment angles leads to the occurrence of large forces in the cables and a decrease in the rigidity of the span structure. However, the scheme with one pylon turns out to be acceptable in urban conditions for architectural reasons, as it can fit into the ensemble of the terrain and buildings of the city near the river.

The pylon of the cable-stayed bridge can be tilted to the vertical. In addition to the architectural effect, it allows to transfer part of the horizontal force from the cables of the main span to the pylon. In single-pylon bridges, the end cables can be attached to the foundations. In this case, the stiffening beam rests against one of the foundations, transferring a horizontal force to it.

Cable-stayed bridges with two pylons (Fig. 6*b*), the outermost cables of which are fixed to the ends of the stiffening beam, work as systems with a perceived gap in the stiffening beam. They have mainly vertical forces transmitted to the pylons from the cables, since their cables are located symmetrically with respect to the pylons. Angles of inclination of the cables are taken at least 30°, so that they do not have significant forces and deformations. The stiffness beam in these bridges can be supported in many points, which is favorable for its operation.

The distances between the points of attachment of the cables to the stiffening beam vary widely: from 5-10 to 50-60 m. Depending on this, the height of the stiffening beam changes. It is usually taken constant along the entire length.

In cable-stayed bridges, various systems of positioning of cables are used. Two cable systems are most often used: "bundle" and "harp". In the "bundle" system (Fig. 7*a*), the cables converge in the upper part of the pylon in one horizontal plane. With many them, it complicates the knot of attaching them to the pylon. In this system, the ropes have different angles of attachment to the stiffness beam, the middle ropes are more inclined to it, which helps to reduce the forces arising in them. With the presence of extreme support cables in this system, there are no bending moments in the pylons, they work only in compression. In the "harp" system (Fig. 7*b*), the cables are attached to the pylon in several levels and have the same slope to the stiffness beam. The knots for fastening the cables to the stiffness beam and to the pylon in it are of the same type. With many cables, this system allows you to unify the knots of fastening the cables to the stiffening beam and to the pylon, unify the elements of the stiffening beam and effectively use the possibilities of their industrial production and construction. However, with one-sided loading of the main span, the pylon works intensively to bend due to the horizontal forces in the cables.

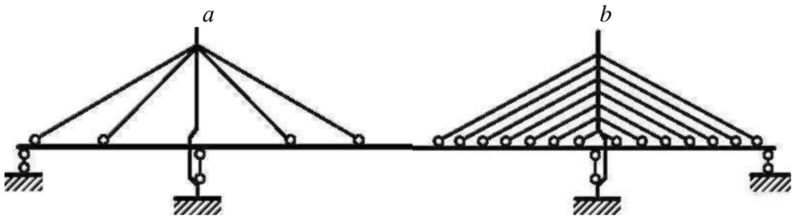

Fig. 7. Schemes of the arrangement of cables in bridges:
a – bundle shape; *b* – harp

In the cross-section of the span structure, the cables are placed in one or two planes. In wide bridges, a larger number of their planes is possible. The number of cable planes and the number of cables in one plane have a significant impact on the architectural merits of the bridge, on the operation and construction of the stiffening beam and pylons.

Types of cable-stayed bridge pylons.

When placing the cables in two planes, П-shaped, A-shaped and two-post pylons are used (Fig. 8*a,b,c*), the driving part is placed between them, and the sidewalks are carried on the console beyond the planes of the cables. When using A-shaped pylons, the cables are placed in two inclined planes, and when using П-shaped pylons, they are placed in two vertical planes. The two planes of the cables make it possible to disperse and reduce the forces in the stiffening beam and in the cables, to ensure favorable operating conditions for the stiffening beam when it is loaded asymmetrically with respect to the longitudinal axis. With two planes of the cables, the stiffness beam can have a small torsional stiffness and be made of tile or ribbed elements.

When placing cables in one plane, single-post (Fig. 8*d*) or A-shaped (Fig. 8*e,f*) pylons are used. In this case, single-post pylons and cables are placed within the width of the dividing strip between the carriageways of the two directions of traffic. Single-post pylons require less material and are easier to manufacture, but the node of their intersection with the stiffening beam is complicated: the pylon must be passed through the stiffening beam while preserving its bearing capacity in the weakening zone. A-shaped pylons (Fig. 8*e,f*) are more difficult to manufacture, but provide free passage of the stiffness beam between its posts and have greater stiffness in the transverse direction.

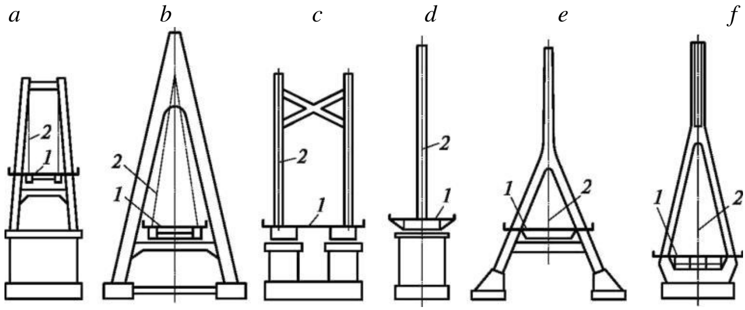

Fig. 8. Constructive forms of pylons in the cross section of an overpass with two (*a–c*) and one (*d–f*) planes of cables:
1 – stiffness beam; *2* - the plane of the cable location

A stiffening beam with one plane of the cables and its asymmetric loading works not only for bending, but also for torsion and should have significant torsional stiffness. The height of the pylons of cable-stayed bridges is taken on the condition that the angle of inclination of the furthest cable-stay is at least 30°.

Construction of cable-stayed bridge elements.

The design of the stiffening beams mainly depends on the width of the carriageway, the number of cable planes, the distance between the points of fastening of the cables and a little on the size of the main span. When the number of cables in one plane increases, it becomes possible to make stiffening beams even from simple unified elements used in simple beam bridges. With two planes of cables, depending on the width of the carriageway and the number of cables in one plane, the stiffening beams can be tiled, ribbed and box-shaped.

Tile stiffeners of cable-stayed pedestrian bridges can be made of unified hollow tile blocks, if the distance between the points of attachment of the cables does not exceed 15…18 m, and the width of the carriageway does not exceed 8 m. longitudinal - monolithic transverse beams. Transverse beams perceive a moment that also bends, acting in the transverse direction; they are also used to attach the stiffening plate to the cables.

As the main span increases, the normal force compressing the stiffening beam increases almost linearly. For its perception, it is necessary to perform a beam of rigidity with a greater height. If the distance between the points of fastening of the cables is 15...30 m, the stiffening beam can be formed from unified I-beams, connecting them at the points of fastening of the cables with transverse monolithic beams - diaphragms capable of perceiving the bending moment in the transverse direction, perceiving the forces from the cables in an inclined plane and transfer them to the longitudinal beams, components of the stiffness beam.

At the same distances between the points of fastening of the cables, a stiffening beam was used, consisting of two widely spaced П-shaped beams, on which the transverse beams of the carriageway are laid. The extreme beams are placed in the planes of the cables, have transverse diaphragms to which the cables are attached. This design of the stiffening beam was first used in the cable-stayed bridge across the Dnipro harbor in Kyiv.

When the width of the carriageway is more than 12 m, it is advisable to use stiffening beams of box section, which have significant torsional stiffness. With a single-plane cable system, only the box-shaped cross-section of the stiffening beam can reliably resist bending and twisting. Box beams have great stiffness during bending and twisting, are equally well adapted to the perception of both positive and negative moments, have good aerodynamic parameters, have an attractive appearance, are convenient for transportation and installation.

Justification of the type of cable-stayed ropes.

Restoration of the destroyed span structures of bridge crossings requires significant material costs and time, as they must have significant bending stiffness in terms of strength and stiffness. Cable-stayed bridges require significantly less rigidity. Depending on the design of the cable-stayed bridge, ropes of different strength and, accordingly, different designs should be used. Cable ropes are not produced in Ukraine, however, the production of composite rubber-cable ropes for the mining industry has been established.

The practice of use under the influence of mining waters and abrasive wear has shown their considerable durability. Accordingly, there is an opportunity to create and manufacture a wide range of composite multi-layer cable-stayed ropes of different tensile strength for holding span structures of bridge structures, which requires scientific and technical justification. The use of such approaches in combination with the use of new materials and structures corresponds to modern world trends, and for Ukraine it is decisive for the strategy of military, post-war, urban, and industrial construction.

To solve the most important problem of the accelerated restoration of destroyed bridge crossings, the development of scientific and applied principles for the creation of a complex technology for the rapid restoration of bridges with destroyed span structures based on the use of composite multi-layer cable ropes of domestic production is relevant.

In Ukraine, most of the roads were built more than 50 years ago. Small and medium-sized bridges on highways are made of prefabricated string concrete diaphragm beams [11–16]. In our opinion, a promising technology for the restoration of bridges destroyed because of military operations is restoration by replacing span structures of bridges with cable-stayed ones as spatial steel-reinforced concrete structures [17-21].

One of the problems of implementing such an engineering solution is the use of the support system of the destroyed bridge and ensuring its reliability during the life cycle. There are at least two options for restoring spans of destroyed bridges: with the installation of a pylon on one of the banks of the river (fig. 9*a*) or with the location of a pylon on an artificially created island (fig. 9*b*).

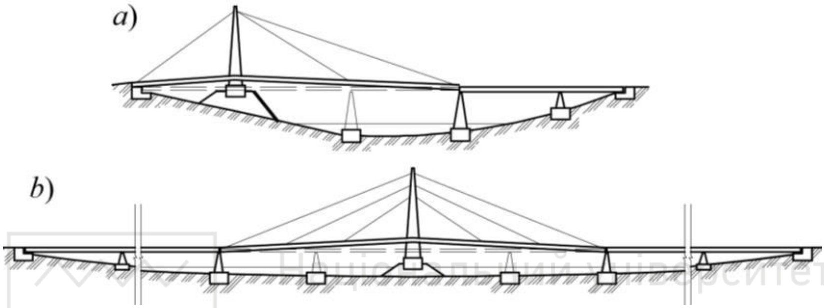

Fig. 9. Schemes of restoration of destroyed bridge spans using pylons with their location on the riverbank (*a*), on an artificial island (*b*)

The given scheme can use the existing, restored or reconstructed supports of the destroyed bridge. Different support systems of a collapsed bridge require different schemes of cable-stayed bridges. The above allows us to state that the developed structures of cable-stayed bridges can be adapted to various layout schemes and surviving supports (their foundations) of destroyed bridges. However, the application of such a proposal is associated with a number of problems:

- the production of wire ropes of a significant range of strength (diameters) requires the involvement of a significant number of suppliers or the construction of facilities with a wide range of production of ropes of various diameters;

- significant resistance to wind (horizontal) loads, accordingly additional deformation of the ropes;

- the reliability of the cable rope can be increased only by increasing its diameter, which leads to an increase in the above-mentioned drawback;

- a rope of a large diameter has a significant bending stiffness, its winding is possible only on coils of a large diameter;
- the influence of the environment on the rope requires its special protection.

In our opinion, a comprehensive solution to these problems is possible by replacing round cable ropes with flat ones, namely rubber-cable ropes (fig. 10). They use small cables of the same diameter as the rope.

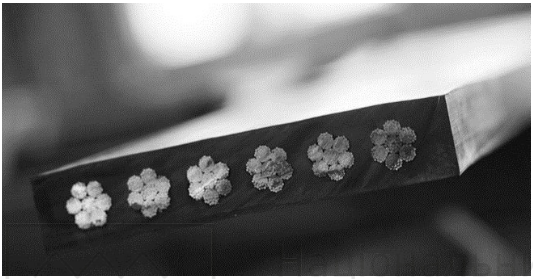

Fig. 10. Rubber-cable rope

The specified strength of the rope can be ensured by the number of cables in it. In addition, the production of such ropes has been established in Ukraine (fig 11).

A rope of a given profile can be formed by gluing single-layer ropes into several layers directly at the installation site. The parallel use of ropes in one rope as in a system with parallel connection and incomplete redundancy allows to ensure the specified durability of the rope by selecting the number of ropes in the rope.

The presence of rubber between the cables allows the method of controlling the electrical resistance measured between the ends of the cables to automatically determine breaks in individual cables during the life cycle, which increases the reliability of its operation. Studies on the substantiation of the method of controlling the electrical resistance of the wire rope are being conducted [22-32].

Today, it is necessary to develop and implement a technology in which to replace the rubber that connects the cables into a single system with another elastic material suitable for use in conditions of natural environmental influences on it.

Within the scope of this technology, it is envisaged to glue flat ropes into a cable rope using portable presses and to give the section of the cable rope an aerodynamic shape.

Methodology of stress-strain state calculating.

We will accept the following calculation scheme. A system of M parallel, flexurally rigid elastic rods of length L interacts through an elastic continuous medium in which tangential stresses arise.

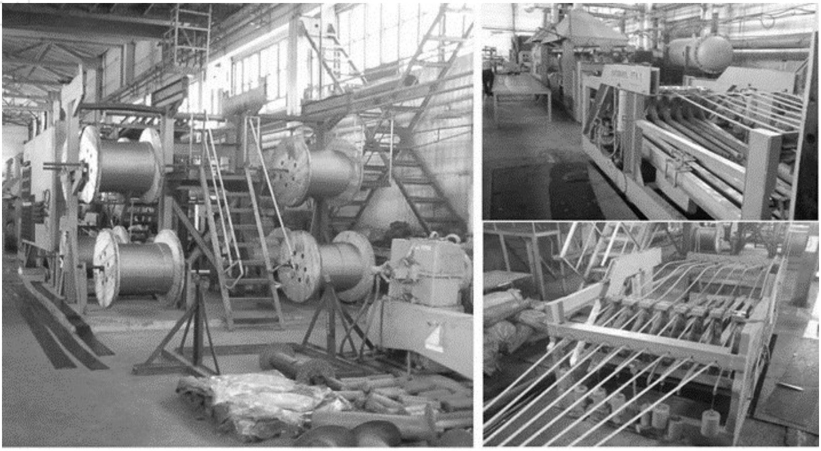

Fig. 11. Line to produce rubber-cable ropes in Kryvyi Rih

Deformation occurs within the linear law. One cable (j^{th}) has a distance discontinuity l $(0 < l < L)$ from the section of fixing the cables. The force P acts on the rope [33].

The solution to the problem looks like this [8, 9]

$$u_i = \sum_{m-1}^{M-1} \left(A_m e^{\beta m^x} + B_m e^{-\beta m^x} \right) \cos\left(\mu_m \left(i - 0,5 \right) \right) + \frac{P x}{E F} + \varepsilon, \quad (1)$$

where A_m, B_m, ε – unknown constants; M – number of cables in the rope; P – tensile strength of the cable; $\mu_m = \pi m/M$; $\beta_m = \pm\sqrt{2\left(\left(G b k_G\right) / \left(h E F\right)\right)\left(1-\cos\left(\mu_m\right)\right)}$; b – rope thickness; c – the step of the arrangement of the cables in the rope; d – cable diameter; G – shear modulus of the rope rubber sheath material; k_G – coefficient that takes into account the cross-sectional shape of the rubber shell; h – the minimum distance between adjacent cables of the rope; E, F – composite modulus of elasticity for tension of the cable material and their cross-sectional area.

Rope tensile

$$p_i = EF \sum_{m=1}^{M-1} \left(A_m e^{\beta m^x} - B_m e^{-\beta m^x} \right) \beta_{m,k} \cos\left(\mu_m \left(i - 0,5 \right) \right) + P . \quad (2)$$

Ropes are attached to structural elements of lifting complexes, capital structures. The connection conditions depend on the design of the connection nodes. We will solve the problem of determining the stress-strain state in a general way – without specifying the conditions for connecting the ends of the rope. According to the task, the rope has a break in the continuity of the rope. This makes it impossible to make decisions (1) and (2) for the rope as a whole. We will apply separate solutions for two parts of the rope. For the first $0 \le x \le l$ and the second $l \le x \le L$ parts of the rope. We will give them the numbers 1 and 2. We will indicate the numbers in the lower index of the value that applies only to the specified part. We will record the movement and load of the cables of the second part in the following forms

$$u_{i,2} = \sum_{m-1}^{M-1} \left(A_{m,2} e^{\beta_m x} + B_{m,2} e^{-\beta_m x} \right) \cos\left(\mu_m \left(i - 0{,}5 \right) \right) + \frac{P x}{E F} + \varepsilon_2 \,, \quad (3)$$

$$p_{i,2} = EF \sum_{m=1}^{M-1} \left(A_{m,2} e^{\beta_m x} - B_{m,2} e^{-\beta_m x} \right) \beta_{m,k} \cos\left(\mu_m \left(i - 0{,}5 \right) \right) + P. \quad (4)$$

The parts of the rope form a single rope of length L. In the section $x=l$, the conditions must be fulfilled

$$p_{i,1} = p_{i,2} \quad \left(1 \le i \le M \right), \quad (5)$$

$$p_{j,1} = p_{j,2} = 0 \,. \quad (6)$$

The size of the gap between the cables in the section of the break depends on the load on the rope. Let's conditionally accept it equal to one. The condition for the occurrence of a single gap between the ends of the damaged cable

$$u_{i,1} - u_{i,2} = \begin{cases} 0 & \left(i \ne j \right) \\ 1 & \left(i = j \right) \end{cases}, \quad (7)$$

where j - cable number with a break in continuity in the section $x = l$.

We equate the last condition with the δ-function. It is given by the Fourier series on the discrete axis of the numbers of cables of limited length:

$$u_{i,1} - u_{i,2} = \frac{2}{M} \cos\left(\mu_m \left(i - 0{,}5 \right) \right) + \frac{1}{M} \,. \quad (8)$$

From conditions (5) and (7), we have the following relations:

$$A_{m,1} - B_{m,1}e^{-2\beta_m l} - A_{m,2} + B_{m,2}e^{-2\beta_m l} = 0\,, \quad (9)$$

$$A_{m,1} + B_{m,1}e^{-2\beta_m l} - A_{m,2} - B_{m,2}e^{-2\beta_m l} = \frac{2}{Me^{\beta_m l}}\cos\left(\mu_m\left(j-0{,}5\right)\right), \quad (10)$$

$$\varepsilon_1 - \varepsilon_2 = \frac{1}{M}\,. \quad (11)$$

After simplifying the expressions (9), (10), we obtain:

$$A_{m,1} = A_{m,2} + \frac{\cos\left(\mu_m\left(j-0{,}5\right)\right)}{M\,e^{\beta_m l}}\,, \quad (12)$$

$$B_{m,1} = B_{m,2} + \frac{\cos\left(\mu_m\left(j-0{,}5\right)\right)}{M}e^{\beta_m l}\,. \quad (13)$$

Let's assume that there are no displacements of the first part ε_1 = 0. Then

$$\varepsilon_2 = -\frac{1}{M} \quad (14)$$

We consider expressions (9) and (10). Let's write down the value of the loading force of the jth cable in the section $x = l$. According to (6), the internal load force of the cable should be zero. To do this, multiply the first component of expression (2) by the ratio of the real value of the gap between the ropes and the one taken in condition (7). Consider (12), (13):

$$p_{i,1} = E\,F\sum_{m=1}^{M-1}\begin{pmatrix} A_{m,2}e^{\beta_m x} + \dfrac{\cos\left(\mu_m\left(j-0{,}5\right)\right)}{M} - \\ -B_{m,2}e^{-\beta_m x} - \dfrac{\cos\left(\mu_m\left(j-0{,}5\right)\right)}{M}\end{pmatrix}. \quad (15)$$

$$\cdot\beta_{m,k}\cos\left(\mu_m\left(i-0{,}5\right)\right)Q + P,$$

where:

$$Q = -P\left[\frac{E\,F}{M}\sum_{m=1}^{M-1}\begin{pmatrix} A_{m,2}e^{\beta_m l} + \cos\left(\mu_m\left(j-0{,}5\right)\right) - \\ -B_{m,2}e^{-\beta_m l} - \cos\left(\mu_m\left(j-0{,}5\right)\right)\end{pmatrix}.\right. \quad (16)$$

$$\left.\cdot\,\beta_{m,k}\cos\left(\mu_m\left(j-0{,}5\right)\right)\right]^{-1}$$

Accordingly, in other expressions for the distribution of forces and movements of cables of the first and second parts, the components of the expressions dependent on the number of the cable must be multiplied by the specified ratio. They determine the tension-deformed state of a rope with a damaged cable.

Two vectors of unknown constants remain unknown in the obtained solutions. They should be determined from the conditions of fixing the ends of the rope in the lifting installation or on the capital structure. These calculations complete the first part of the algorithm for calculating the stress-strain state of the rubber-cable rope.

Consider the influence of the nonlinear dependence of the modulus of elasticity on the applied force. Consider the second part of the algorithm. The lack of resistance to deformation of the damaged cable is accompanied by a redistribution of internal load forces between other (whole) cables. According to the Saint-Venant principle, a local change in the shape of a rigid body, as well as the application of a concentrated force, leads to a local redistribution of forces in an elastic body - in a rope. The internal load forces of the cables adjacent to the damaged one increase significantly. The tension in the cables adjacent to the damaged one is significantly (up to 60-40%) higher than the average.

It is known that the modulus of elasticity of materials depends on the load force, when the stresses in the loaded sample exceed a certain value - the limit of elasticity. Accordingly, the non-linear deformation of ropes with an uneven distribution of forces between the ropes can be modeled linearly, in which the deformations are considered unchanged, and the maximum forces are taken as reduced in proportion to the ratio of the modulus of elasticity, which corresponds to the actual load to its linear value.

The law of decreasing internal load forces of maximally loaded ropes is given by the product of Fourier series in continuous coordinates on the first and second parts in the intervals $0 \le x \le l$ and $l \le x \le L$ and in discrete coordinates of cable numbers, limited by their number. Thus, the model of the deformed state and the obtained dependencies for the case of linear deformation of the rope (1), (3) remain unchanged. Ratios (12), (13) obtained from the conditions of simultaneous deformation remain unchanged. Expression (14) will depend on the quantity ψ тросів, cables adjacent to the damaged one:

$$\varepsilon_2 = -\frac{\psi}{M}. \qquad (17)$$

Expressions of internal load forces of cables (2), (4) are written in the following forms:

$$p_{i,1} = EF\sum_{m=1}^{M-1}\left[\begin{array}{l}\left(\begin{array}{l}\left(A_{m,2}+\dfrac{\cos\left(\mu_m\left(j-0,5\right)\right)}{M\,e^{\beta_m l}}\right)e^{\beta_m x}-\\ -\left(B_{m,2}+\dfrac{\cos\left(\mu_m\left(j-0,5\right)\right)}{M}e^{\beta_m l}\right)e^{-\beta_m x}\end{array}\right)\beta_{m,k}-\\ -\sum\limits_{k=0}^{K}C_{k,1}\cos\left(\dfrac{\pi kx}{l}\right)\left(\begin{array}{l}\cos\left(\mu_m\left(j-1,5\right)\right)+\\ +\phi\cos\left(\mu_m\left(j+0,5\right)\right)\end{array}\right)\end{array}\right]\cdot, \qquad (18)$$

$$\cdot\cos\left(\mu_m\left(i-0,5\right)\right)+P$$

$$p_{i,2} = EF\sum_{m=1}^{M-1}\left[\begin{array}{l}\left(A_{m,2}e^{\beta_m x}-B_{m,2}e^{-\beta_m x}\right)\beta_{m,k}-\\ -\sum\limits_{k=0}^{K}C_{k,2}\cos\left(\dfrac{\pi kx}{L-l}\right)\left(\begin{array}{l}\cos\left(\mu_m\left(j-1,5\right)\right)+\\ +\phi\cos\left(\mu_m\left(j+0,5\right)\right)\end{array}\right)\end{array}\right]\cdot,$$

$$\cdot\cos\left(\mu_m\left(i-0,5\right)\right)+P \qquad (19)$$

where $C_{k,1}$, $C_{k,2}$ - coefficients of the Fourier series, which take into account the difference between the linear modulus of elasticity of the cable and the real one, depending on the load; ϕ – the coefficient of proportionality of the load forces of the $(j + 1)^{th}$ cable relative to the $(j–1^{th})$.

From the condition of equality of forces (5), the condition of equality between the coefficients must be ensured:

$$\sum_{k=0}^{K} C_{k,}\cos\left(\pi k\right) = \sum_{k=0}^{K} C_{k,2}\cos\left(\frac{\pi k l}{L-l}\right). \qquad (20)$$

The value of the Q coefficient will change. It will be determined by the following dependence:

$$Q=-P\left[\sum_{m=1}^{M-1} E\,F\left(\begin{pmatrix} M\,A_{m,2}e^{\beta m l}+\cos\left(\mu_m\left(j-0{,}5\right)\right)- \\ -M\,B_{m,2}e^{-\beta m l}-\cos\left(\mu_m\left(j-0{,}5\right)\right)\end{pmatrix}\frac{\beta_{m,k}}{M}- \atop -\sum_{k=0}^{K} C_{k,1}\cos\left(\pi k\right)\begin{pmatrix}\cos\left(\mu_m\left(j-1{,}5\right)\right)+ \\ +\phi\cos\left(\mu_m\left(j+0{,}5\right)\right)\end{pmatrix}\right)\cdot\right. \qquad (21)$$

$$\left.\cdot\cos\left(\mu_m\left(j-0{,}5\right)\right)\right]^{-1}$$

Note that expression (20) is obtained for the general case when not the outermost cable is damaged. For the damaged extreme (first) cable, expression (20) lacks an element $\cos\left(\mu_m\left(j-1{,}5\right)\right)$. In case of damage to the cable number M, the element is missing $\phi\cos\left(\mu_m\left(j+0{,}5\right)\right)$.

The coefficient Q is determined considering the difference in force distributions determined for the conditions of linear deformation and taking into account nonlinear deformation. The first components of the distribution of deformations and forces must be multiplied by it.

Finally, the calculation algorithm consists in determining the tension-deformed state of the rope under the conditions of linear deformation of the ropes using expressions (1)-(4), (9), 10, (12-(14), (16). Determine two unknown constant vectors from the conditions of connecting the ends of the rope to the structure or elements of the lifting machine. According to the determined distributions of forces in the ropes adjacent to the damaged one, choose the laws of force change. It should compensate for the excess of the calculated (linearly dependent) efforts over the actual ones, determined taking into account the differences in the values of the linear and non-linear modulus of elasticity. According to the defined laws, determine the coefficients of the Fourier series $C_{k,1}$, $C_{k,2}$. Substitute the values of the coefficients into expression (21). Find the value of the coefficient Q. Multiply by it the first components of the values of the internal load forces of the cables in expressions (19), (20) and displacements in expressions (1), (3). To obtain the desired displacements of the cables and the distribution of forces between them in a rope of a given design with a damaged arbitrary cable under the given conditions of connecting the ends of the rope.

Study of the stress-strain state of rubber-cable rope. Consider the main rope of a lifting machine with M cables and length L. We direct the x axis along the rope. Its beginning is in the cross-section of the connection to the machine element - to the pulley. The pulley is tilted at an angle ψ. The ropes are hinged to it at the cross-section $x = 0$. A load $x = L$ is attached to the other end. The cross-section of the rope, located normal to the deformation (load), remains normal to the axis of the rope and after the load [34].

We will formulate the boundary conditions for the adopted scheme

$$x = 0, \quad u_i = (i - 0{,}5)t\psi \quad \left(-\frac{M}{2} < i < \frac{M}{2}\right); \tag{22}$$

$$x = L, \quad u_i = 0, \tag{23}$$

where t – the pitch of the cables in the rope.

We write the boundary condition (22) in the form of a Fourier series

$$x = 0, \; u_i = \frac{2t\psi}{M} \sum_{j=1}^{M} (j - 0{,}5)\cos\left(\mu_m (j - 0{,}5)\right). \tag{24}$$

In the general case, the stressed-strained state of a flat rubber-cable rope is determined by the following dependencies [4, 5]

$$u_i = \sum_{m=1}^{M-1} \left(A_m e^{\beta_m x} + B_m e^{-\beta_m x}\right)\cos\left(\mu_m (i - 0{,}5)\right) + \frac{Px}{EFM}, \tag{25}$$

$$p_i = EF \sum_{m=1}^{M-1} \left(A_m e^{\beta_m x} - B_m e^{-\beta_m x}\right)\beta_m \cos\left(\mu_m (i - 0{,}5)\right) + \frac{P}{M}, \tag{26}$$

$$\tau_i = \frac{G}{h}(u_i - u_{i+1}), \tag{27}$$

where A_m, B_m - vectors of proportionality coefficients; P - rope load force; E, F - combined tensile stiffness and cross-sectional area of the cable; M - number of cables in the rope; $\mu_m = \frac{\pi m}{M}$;

$\beta_m = \sqrt{\frac{2Gbk_G}{(t-d)EF}(1 - \cos\mu_m)}$; b – rope thickness; d, h - the diameter of the cable and the minimum distance between the adjacent cables of the rope; G, k_G shear modulus and a coefficient that takes into account the influence of the shape of the layer of elastic material located between the cables.

We use boundary conditions (23) and (24). Let's determine the values of the vectors of proportionality coefficients of expressions (25)-(27

$$B_m = \frac{2t\psi}{M\left(1 - B_m e^{-2\beta_m L}\right)} \sum_{j=1}^{M} (j-0,5)\cos\left(\mu_m (j-0,5)\right),$$

$$A_m = -B_m e^{-2\beta_m L}.$$

As an example, the stress state indicators of the GTK-3150 type rubber-cable rope with ten cables, 10 m and 5 m in length, were calculated under the condition ψ = 0.01 degree. The results are shown in Fig. 12.

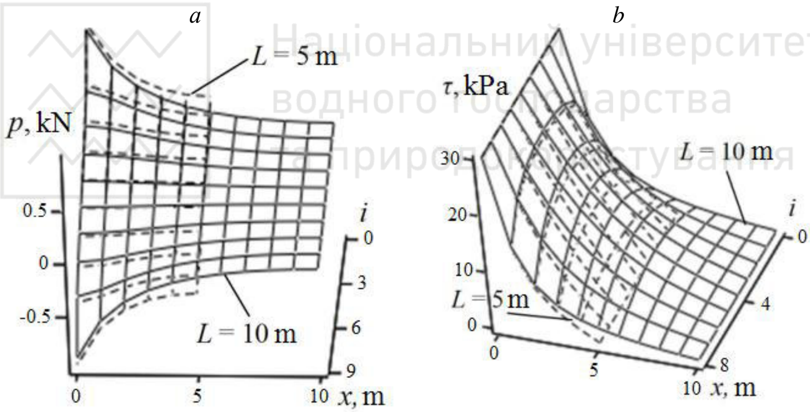

Fig. 12. Distribution graphs: *a* - internal forces *p* load of cables by numbers *i*; *b* - the maximum tangential stresses *τ* in the rubber layers along the axis of the rope *x* in the case of rotation of the pulley in the plane of the rope

In the absence of rotation of the end of the rope in the section $x = 0$ and rotation of the opposite end $x = L$, the coefficient vectors of expressions (4) – (6) are determined by the following dependencies

$$B_m = \frac{2t\psi}{M e^{\beta_m L}\left(e^{-2\beta_m L} - 1\right)} \sum_{j=1}^{M} (j-0,5)\cos\left(\mu_m (j-0,5)\right),$$

$$A_m = -B_m .$$

The results are asymmetric to the results of the previous case because the boundary conditions are asymmetric. At the same time, the linearity of the problem, the given forms of the solutions allow us to determine the stressed-but-strained state for the cases of the combination of different schemes of rotation of sections $x = 0$ and $x = L$. In the case of rotation of both edges, after removing asymmetric cases, we have two schemes. Let's look at them. For this purpose, we will add additional indices 0 and L to the designations of the angles of inclination of the specified sections, respectively. The coefficients will take on the following values

$$B_m = \frac{2t}{M}\left(\frac{\psi L}{\left(1 - B_m e^{-2\beta_m L}\right)} + \frac{\psi 0}{e^{\beta_m L}\left(e^{-2\beta_m L} - 1\right)}\right) \cdot$$

$$\cdot \sum_{j=1}^{M} (j - 0{,}5)\cos\left(\mu_m (j - 0{,}5)\right),$$

$$A_m = -B_m\left(e^{-2\beta_m L} + 1\right).$$

Please note that the values of the angles must be substituted taking into account the sign of the direction of inclination.

For the conditions of the previous example, we considered the cases of equal rotation of both edges according to the absolute values of the angles in the same and opposite directions. The results of the calculations are shown in Fig. 13 and 14.

A comparison of the intervals of the maximum values of the internal load forces of the ropes and the maximum tangential stresses in the material of the rope sheath shows that turning the ends of the rope at equal angles does not affect their values.

Only the amplitude of the change of these values along the length of the rope decreases. The latter testifies to the effect of rope properties on the zone of manifestation of localization of disturbances.

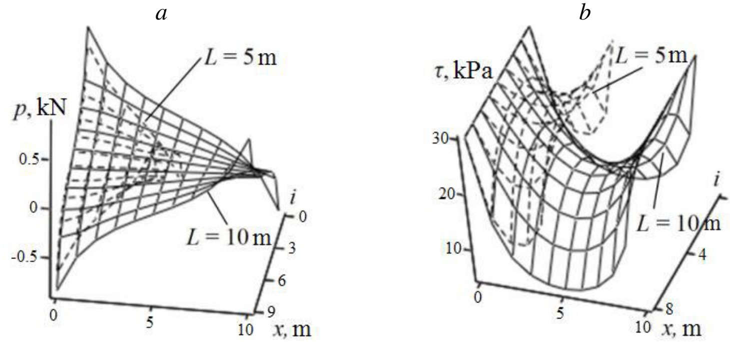

Fig. 13. Distribution graphs: *a* - internal forces *p* load of cables by numbers *i*; *b* - maximum tangential stresses *τ* in the rubber layers along the axis of the rope *x* in the case of equal turns of its ends

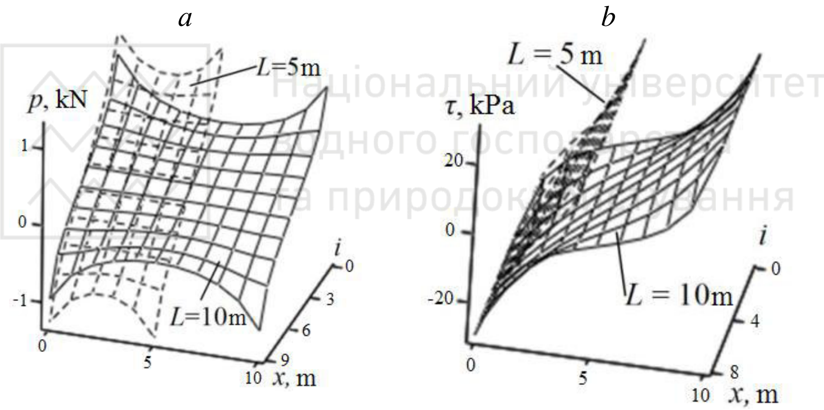

Fig. 14. Distribution graphs: *a* - internal forces *p* load of cables by numbers *i*; *b* - maximum tangential stresses *τ* in the rubber layers along the axis of the rope *x* in the case of opposite turns of its ends

A comparison of the dependencies (Fig. 13) and (Fig. 14) shows that turning the ends of the rope in opposite directions leads to an increase in the load forces of the cables by almost two times. Strength also increases with a decrease in the length of the rope. This is also a manifestation of overlapping zones of two disturbances. Due to the opposite rotation of the sections in the middle (longitudinal) part of the rope, tangential stresses are absent and do not depend on the length of the rope.

The indicated scheme of bends is the most dangerous from the point of view of rope strength. Considering equally possible turns in opposite directions of the cross-sections of connecting ropes, the strength condition must be ensured for the last case.

According to dependencies (25) – (27), the stress-strain state of the rubber rope along its own axis changes in proportion to the exponential functions $e^{\pm\beta_m x}$. The value of the vector β_m depends on the square root of the product of two parameters. The first one depends on the mechanical properties of the components of the rope and the geometric parameters of the cross-section of the elastic sheath located between adjacent cables. The second is the root of the cosine function of the number of ropes in the rope. The growth of each lead to a proportional increase in the lengths of the areas of manifestation of local disturbances. The first is proportional to the value $\sqrt{\frac{2Gbk_G}{(t-d)EF}}$. The second, as the performed analysis shows, is practically proportional to the three-fold increase in the number of cables in the rope.

Separately, we note that for ropes of considerable length, when the effects of marginal perturbations of stress states are not superimposed one by one, the following values of vectors of unknown coefficients can be used:

$$B_m = \frac{2t\psi}{M}\sum_{j=1}^{M}(j-0{,}5)\cos\left(\mu_m(j-0{,}5)\right),$$

$$A_m = 0\,.$$

Due to the absence of superposition of stress disturbances, the origin of the coordinate axis can be assumed to be in the cross-section of each end of the rope.

Extreme stress values are reached in the cross-sections of the rope connection ($x = 0$ or $x = L$) in the outermost cables and in the outermost layers of rubber. The known stresses make it possible to determine the admissibility of using the rope under the specified conditions.

Consider the case of rotation of the vessel around its own axis by an angle ψ. From the point of view of geometry, the axes of the centers of the cross-sections of the ropes of the section connecting the rope to the drum or to the vessel are located on passing straight lines. The latter are in planes normal to the axis of the rope. The angle between the projections of passing lines on the plane normal to the axis of the flat rope corresponds to the angle of rotation of the vessel relative to the drum ψ. The movement of the generator along the guide, located at a right angle to it, with its simultaneous rotation around the guide, forms a straight helicoid. Accordingly, provided the distance between the axes of the ropes remains unchanged, the flat rubber-cable rope takes the form of a straight helicoid. Ropes are in the form of spiral lines. At the same time, the centers of the cable sections remain on straight lines - the hypothesis of flat sections is fulfilled, but the cables have a constant length of the rope and a relative elongation that depends on the location in the rope. The indicated elongation is proportional to the distance of the rope from the axis of the rope and the angle of rotation of the vessel and is inversely proportional to the length of the rope. Absolute elongations related to the initial dimensions are relative elongations. Known elongations and Hooke's law make it possible to determine the distribution of forces between the cables.

Based on the above, we have the expressions of movements and distribution of forces in the cables of a flat rubber-cable rope connected to the elements of the machine, when the centers of the rope sections of the rope are located on passing straight lines.

$$u_i = \frac{P x}{E F M},$$

$$p_i = E F \left[\sqrt{\left(\left(\frac{M}{2} - i \right) \frac{t \psi \pi}{L} \right)^2 + 1} - 1 \right] + \frac{P}{M}.$$

Objectively, the most heavily loaded are the outer ropes of the rope. There are no tangential stresses caused by the shift of the cables along the axis of the rope.

Supports for pylons.

It should be noted that the construction of pylons on the banks of the river bed can lead to landslides and collapses, and as a result, the destruction of the bridge. To prevent this, it is advisable to use retaining walls. Retaining walls are artificial structures designed to keep the mountain massif from collapsing. Retaining walls are divided by purpose, height, component material, angle of inclination of the back face, principle of operation, and also by the method of construction.

The retaining wall is subjected to various loads, including the wall's own weight, the pressure of the mining massif, the pressure of the weight of structures (supports, pylons) located on the supported massif, the pressure of construction equipment, and the pressure of water.

It is worth noting that riverbanks are the zone of action of groundwater. To prevent their negative impact on the wall at its base from the side of the mountain massif, a drainage system is usually built. However, this involves additional costs.

At the same time, there are walls of this design that do not require drainage systems. They consist of mesh gabion products (fig. 15).

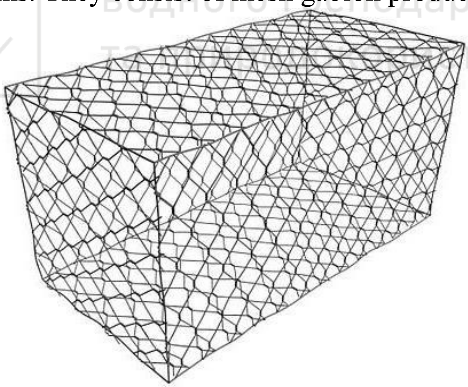

Fig. 15. 3×1×0,5 m Box-woven mesh gabion [36]

Gabions are metal containers of various shapes, consisting of a double-twisted metal mesh, which are filled with stone material. They are designed to create strong, flexible, and permeable massive supporting structures. The main types of gabions are mattress-tuff and box gabions. When erecting retaining walls on loose soils, gabions with a reinforcing panel are used. In recent years, gabions have gradually supplanted monolithic supporting structures, gaining in cost and quality [35].

The process of installing a retaining wall is as follows. The gabion is laid out on a hard flat surface, then walls and a diaphragm are attached to its bottom, which strengthen the structure. Then the walls and the diaphragm are connected in such a way as to obtain a capacity in the form of a parallelepiped.

After that, adjacent gabions relate to special stiffening membranes and reinforcing hooks are installed. Then formwork is installed along the length of the structure to prevent deformation of the gabions and filled with stone material, after which all operations are repeated.

Retaining walls made of mesh gabion products are used to hold soft rocks, fence highways and railway tracks, when erecting bridges and creating terraces on homesteads, as well as coastal fortifications of riverbeds. The construction of reinforced concrete structures requires a lot of labor and has a high cost.

In Ukraine, the production of gabions has been established, and there is also rich experience in the construction of engineering structures from them (fig. 16).

Fig. 16. Transport tunnel. Kyiv - Kharkiv – Dovzhanskyi [37]

Formation of an artificial island.

Damaged bridge supports must be converted into pylons. To increase the reliability and bearing capacity of the pylons, as well as to partially relieve the load on the cables, it is proposed to build artificial islands for wide rivers. For this, it is suggested to use a tower excavator [38-40].

At the beginning of the construction of the artificial bridge, overburden rocks are delivered to one of the banks of the river by dump trucks and stacked with a stable arrangement of the dump embankment, which is characterized by a minimum distance of rock transportation. On an undisturbed stable base, the drive support of the tower excavator is installed and at a safe distance from it, a receiving bunker is formed for the accumulation of overburden rocks. At the same time, the tail support of the same tower excavator is installed on an intact stable base near the opposite bank of the river. The supports of the tower excavator are connected by hanging, tail and traction ropes, which move the scraper (fig. 17.). These ropes are made of composite material and will be used as cables of this bridge in the future.

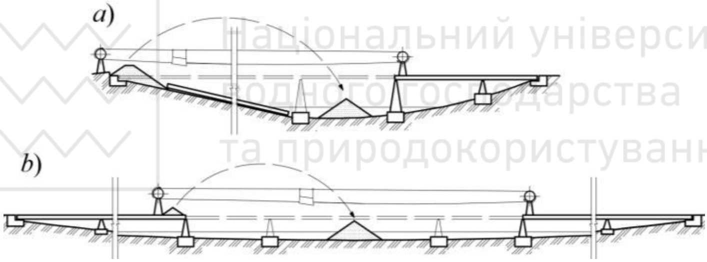

Fig. 17. Scheme of construction of an artificial island with a tower excavator: *a* – with the tower located on the riverbank, *b* – with the towers located on the not disturbed bridge sections

The delivery of rocks is carried out by plunging the bucket scraper under its own weight to the pile of rock in the receiving bunker and then moving it along the suspension rope to the place of unloading.

Alternatively, to reduce the length of the ropes, the supports of the tower excavator can be installed on the surviving bridge flights.

This solution allows you to quickly build an artificial island on a section of the river with an intense current, strengthen it with retaining walls, and then start building a pylon on it. The presence of an artificial island greatly simplifies and speeds up construction.

Conclusions.

The possibility of restoring bridges of Ukraine destroyed during military operations is shown. As an alternative to the restoration of destroyed bridges, it is proposed to install cable-stayed bridges. Well-known rubber-cable ropes, the production of which was established in Ukraine, were used as cable ropes. The reliability of the proposed ropes can be increased by increasing the number of ropes in them.

The existing experience in the construction of cable-stayed bridges, a wide raw material base, as well as the production of necessary materials allow us to assert the prospects of the direction of post-war reconstruction of destroyed bridges with the conversion of damaged supports into pylons. It is proposed to increase the reliability of the converted pylons and the bearing capacity of the bridge by strengthening the sides of the riverbanks with gabion retaining walls or by constructing an artificial island.

A model and algorithm for calculating the stress-strain state of a rubber-cable rope of arbitrary design, considering the nonlinear deformation of the ropes and the presence of a discontinuity of an arbitrarily located rope, has been developed. The model was built using the methods of the mechanics of composite materials. It is solved analytically in a closed form. The resulting algorithm can be considered sufficiently reliable and such that it allows you to reasonably determine the conditions for the safe use of rubber-cable ropes in case of damage to an arbitrary rope.

Analytical expressions are constructed in the work, which allow to determine the quantitative indicators of influence on the stress-deformed state of the rubber-cable rope of the turns of the cross-sections of its connection to the elements of the lifting machine and the rotation of the vessel around its longitudinal axis.

The equal inclination of the cross-sections connecting the ends of the rope in opposite directions compared to turning in one direction practically leads to a double increase in the load forces of the cables. The lengths of the areas of manifestation of local disturbances depend on the square root of the product of two parameters. The first depends on the mechanical properties of the components of the rope and the geometric cross-section parameters of the elastic sheath located between adjacent cables. The second is the root of the cosine function of the number of cables in the rope. The growth of each lead to a proportional increase in the lengths of the areas of manifestation of local disturbances. At the same time, the increase is proportional to the threefold increase in the number of ropes in the rope. Extreme stress values are reached in the cross-sections of the rope connection in the outermost ropes and in the outermost layers of rubber. The rotation of the vessel around the longitudinal axis of the rope is accompanied by the acquisition of the shape of the surface of a straight helicoid by the rope, and helical lines by the cables. The radii of the helical lines are proportional to the distances to the cables from the rope axis.

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ANTHROPOGENIC IMPACT OF MINING SOLID WASTE ON ENVIRONMENTAL POLLUTION AND WAYS TO RESTORE THE ECOLOGICAL BALANCE

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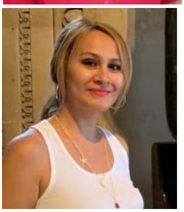

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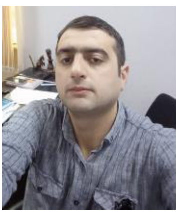

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“All objects in nature have power and people resist in different ways what to win them, a person places otherobjects among them nature"
Georg Wilhelm Friedrich Hegel

The presented work highlights and summarizes the issues of the negative impact of solid industrial waste from a number of industries. It is noted that as a result of human activity, the structure of the biosphere has changed dramatically i.e. atmosphere, relief, living world, etc. of the earth's surface. The historical facts of the occurrence of anthropogenic impact on the environment are analyzed. The main sources of pollution of the ecosphere are shown, such as oil, oil refining, non-ferrous metallurgy enterprises and a number of other industries. It is noted that the irrational use of natural resources has a particularly acute effect on the change in flora and fauna, the destruction, and sometimes the complete disappearance of many species of plants and animals, on unwanted nutrients in the environment (soil, water, air), on the spread of pathogens of infectious and parasitic diseases and pests of agricultural plants and animals, microbiological contamination, etc. It is shown that the metallurgical industry is one of the main polluting industries and accounts for about 40% of the total emissions of the entire industry. On the example of the Dashkesan mining deposit, the questions of the expediency of determining regularities of acid washing of economically valuable metals in mineral waste during iron ore processing. It is concluded that it is necessary to carry out a number of measures to prevent environmental pollution.

Introduction

As a result of human economic activity, there was an anthropogenic impact on the biosphere, i.e. the relief, chemical composition, atmosphere and living world of the earth's surface has changed [1,16]. It should be noted that the emergence of anthropogenic impact is historical, up to the industrial era (18th century), but then environmental pollution did not spread locally and covered large areas. The population of the globe was least quantity, natural resources were in abundance, as a result of which the results of anthropogenic impact were not significantly noticeable [2,18,20]. With the advent of agriculture and animal husbandry, the impact on the biosphere increased, and as a result of grazing over large areas, deforestation and plowing of meadows, and the expansion of agricultural land, natural ecosystems were destroyed and the balance in the biosphere was disturbed.

The industrial period of anthropogenic impact reached its peak in the 20th century, and at this stage all ecological components of the biosphere were subjected to strong anthropogenic impact and global ecological contrasts arose, although until the 17th century the ecological balance in the biosphere was prevent globally, and environmental pollution was of a local one. Since the 17th century, the rapid development of industry has become the main factor destabilizing the biosphere [3,42-47]. At the Davos Economic Forum (2002), American scientists presented about rating of ecological purity of 142 countries of the world, where experts analyzed data on a set of parameters (the state of the environment, the degree of exposure of the country's inhabitants to environmental threats, the ability of the country's government to withstand eco-catastrophes, etc.) and came to the conclusion that the anthropogenic impact on the biosphere manifests itself in the following forms: - changing the structure of the lithosphere, planting greenery in damp lands, steppes and meadows, clearing large areas through the destruction of forest cover, desertification, land reclamation and irrigation works, creation of artificial reservoirs and lakes, etc. In January 2003, the UN once again proclaimed that strategic environmental assessment should be the basis of political and legislative actions, and human health should be an integral part of this assessment [4,15,19]. In the process of economic development, humanity has become directly dependent on the level of energy consumption, in the maximum and full use of hydrocarbon resources, oil and gas, which consists in the discovery and development of new deposits and an increase in the flow rate of previously operated oil wells. The development of oil and gas fields at sea and on land, in turn, required the development of significant problems - organizational, technical, environmental, legal, technological and many others, with a special place given to environmental protection.

Currently, the main sources of pollution of the natural environment are waste oil, oil refining, energy, non-ferrous metallurgy enterprises and a rain of other fields industries. In this aspect, environmental pollution by industrial waste accurate during the development, processing and use of natural resources is an environmental consequence of anthropogenic impact on the biosphere, therefore the biosphere is polluted by initial and secondary waste. Anthropogenic pollution of the biosphere is estimate due to industry: energy and transport (76% in total), of which the share of industry is 38%, energy - 22%, vehicles - 16%, agriculture - 14%, household waste - 7% , other sources - 3% [5, 24-28]. It should be noted that up to 200 natural resources are currently used.

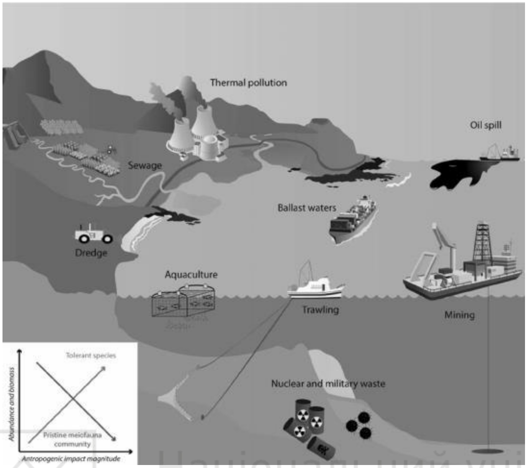

Fig. 1. Anthropogenic impact on the ecosphere

The lack of improvement of modern technology does not ensure the complete processing and use of mineral raw materials. Most of it is returned to nature as waste. According to some reports, the produced product is only 1-2% of the raw materials used, and the rest goes to waste [6, 31-37]. This fact, in addition to confirming environmental pollution, indicates an attitude towards the irrational use of natural resources and the absence of a cost-effective approach. The consequence of this was a change in biota (a set of flora and fauna), the destruction, and sometimes complete disappearance of many species of plants and animals, the creation of new breeds of animals and plant varieties, the loss of biological diversity, unwanted nutrients in the environment (soil, water, air) and the appearance new organisms in a certain area, the spread of pathogens of infectious and parasitic diseases and pests of agricultural plants and animals, microbiological contamination, etc. [7,17,18]. According to the World Health Organization, about 500,000 chemical compounds are currently used in practice, about 40,000 of them harmful to humans, and 12,000 are toxic [8, 53-57].

Environmental problems of mining

The oil and metallurgical industries are one of the significantly polluting field environment [9, 20-23]. So, the share of metallurgy in the total amount of emissions of the entire industry of Russia accounts for about 40% of gross emissions of harmful substances, of which about 34% for gaseous substances, about 26% for solids, then in general, the energy industry in terms of emissions into the atmosphere accounts for 26,6%, non- ferrous metallurgy can be considered one of the leaders in environmental pollution. Large non-ferrous metallurgy enterprises are not only powerful pollutants of the air basin, but also of soil cover, both in terms of intensity and variety of pollutants [10, 38-41].

Fig. 2. Dirty solid waste effluents

Intensive mining and processing of natural resources contributes to an increase in waste and the emergence of a number of environmental problems, i.e. to an increase in solid waste [11,29,30]. It is a fact that the main sources of environmental pollution are concentrated in megacities - industry, energy and transport, which directly affect the ecological situation in the field of environmental pollution and degradation of the biosphere. Sources polluting the biosphere are very diverse (industry, energy, transport, household waste, agriculture, etc.) in composition a large number of chemical compounds, heavy metals, electromagnetic and radioactive radiation, solid waste.

Fig. 3. Main water pollutants

The results and scale of the anthropogenic affect on the biosphere during one year are as follows: 300 billion are mined in minerals, including 100 billion tons of iron ore; during construction and mining operations, 4 thousand km3 of soil and rocks are transported; 800 million rubles tons of various metals are melted down; 50-70 thousand km^2 of land becomes unusable (desertification, salinization, construction, etc.) 18 million rubles. A hectare of forest land is being destroyed; about a thousand species of plants and animals are being lost;

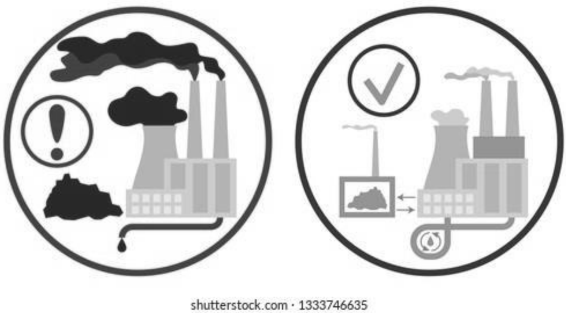

Fig. 4. Ways to eliminate anthropogenic pollution

In particular, the characteristic polluting elements of both wastewater and soil are heavy metal ions and various organic substances that are part of oil and oil products. Such the extraction, processing and transportation of oil and products of its processing also create the risk of man-made accidents and disasters associated with the pollution of waste areas. Accidents on oil pipelines, due to oil spills, through holes formed due to corrosion, lead to losses of transported oil, causing great harm to the environment. An analysis of the research conducted in this area indicates the presence in this area of a number of unresolved fundamental problems in the field of petroleum chemistry associated with the cost-effective and economical operation of oil and gas wells [12, 50-52]. Minimization of the negative anthropogenic impact on water bodies is possible with the improvement of existing, the development of new methods and technologies for the treatment of polluted wastewater from various pollutants. The accumulation of industrial waste leads to local environmental disasters and global problems such as the greenhouse effect, acid rain.

Deciding the problem of environmental pollution with industrial waste is a complex of serious problems that require systemic and urgent ones. In the direction, special attention should be paid to ensuring the safe handling of waste, initially more hazardous. Storage of some wastes under the ground layer is not always safe, which is due to the need for the disposal of man-made wastes and the integrated use of processed products [13,48,49], deposits of natural resources in the Republic of Azerbaijan, and some of them contain a large number of precious metals. For example, since the beginning of XVIII, more than 90 million tons of iron ore have been processed at the deposit of the Azerbaijan Rocks and Processing Plant, and as a result of the processing of this or 46,5 million tons of waste have been obtained. Solid wastes from the processing of mineral raw materials (alunites, bauxites, polymetallic ores) accumulate in large quantities in dumps, which leads to the loss of valuable components, causing significant damage to the state. Several types of mineral waste have been identified: such as quarry rocks, rocks of loose ore layers, waste from an iron ore processing plant, waste from cobalt and alunite deposits containing a significant amount of heavy and non-ferrous metals (Co, Cu, Mn, Zn, Cd, Pb, Fe, Al, Cr, V, etc.). The extraction of related components in non-ferrous metallurgy remains at the level of 10-30%, rarely 50%, although their cost is about 30% of the cost of all marketable products [1, p.323]. The largest waste generated during the production of aluminum is called red clay, which got its name because of its color, acquired due to a large amount of iron oxides (up to 60 wt.%).

An analysis of the literature review showed that a sufficient number of studies have been carried out on the purification of technogenic solutions from metal ions.

The issues of processing waste from metallurgical production remain very relevant for the domestic metallurgy. It is inexpedient to process these difficultly enriched wastes using the existing methods of chemical processing. At the same time, the mineral and chemical composition of the wastes of the Dashkesan ore basin is completely different from the enrichment products found in foreign countries. In this aspect, the question arises of bringing to the fore the development of new processing methods that expand the raw material base for the production of valuable components and rationally use natural resources.

The initial task for the Dashkesan field was to determine patterns of acid washing of economically viable metals in mineral waste from iron ore processing and prevention of environmental pollution. Was defined granulometric, chemical and mineralogical composition of wastes and factors that ensure the transition of metals from wastes into solution and a technological scheme for the extraction of valuable metals (Co, Cu, Zn, Mn) is proposed, about ensuring the protection of the environment, which is one of the most global problems of our time and allowing for the complex processing of waste. Research in this direction were aimed at solving problems from priority areas aimed at for the complex processing of ore processing waste.

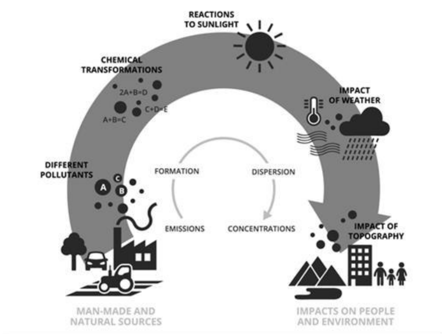

Fig. 5. Industrial pollution of the ecosphere

The problem of processing solid waste - red shlam - is especially acute for enterprises located on fertile lands (Gyanja, Azerbaijan), due to the withdrawal of these lands from agricultural use.

The chemical composition of red mud, depending on the processing method and the type of bauxite and their deposits, is presented in Table 1.

Table 1

The chemical composition of solid waste (red mud) from various fields

Company name (country)	Bauxite deposit	Chemical composition, wt.%					
		Al_2O_3	Fe_2O_3	SiO_2	Ca O	Na_2O	TiO_2
alumina plant -(Azerbaijan)	Dashkesan	14,0	40,0	9,4	14,2	3,8	4,1
clay plant (Ukraine)	Guinean	12,2	56,1	4,6	7,7	2,1	5,4

Analysis of these tables shows that red mud contains a large amount of aluminum and iron oxides.

Research into the recycling of red mud is being conducted around the world and hundreds of methods have now been developed for its disposal. One of the ways in which sludge is used in metallurgy is as additives to the charge, as well as as a raw material for the extraction of iron by the non-domain method and as catalyst-forming masses, catalysts and adsorbents [14].

Wastes received from the processing of the Dashkesan ore basin, from the enrichment of iron ore located in the valley of the Goshgar River, which pose a great threat to the ecological state of its waters.

Table 1 shows the characteristics of the oxen of the river Goshkar on the territory of the field.

Table 2

Characteristics of the water of the Goshkar River

Water indicators		
Name of analyzes	Test results	units of measurement
pH	6	
EC25 _	0,9	ms/sm
Nitrogen (N)	0,01	%
Phosphorus (P_2O_5) mq/kq	8	ppm
Potassium (K_2O) mq/kq	thirty	ppm
Calcium, Ca mq/kq	177	ppm
Magnesium, Mq, mq/kq	24	ppm
Sodium, Na, mq/kq	33	ppm

Iron, Fe, mq/kq	0,05	ppm
copper Cu mq/kq	0,02	ppm
Zinc, Zn, mq/kq	0,045	ppm
Manganese, Mn, mq/kq	2	ppm
Aluminum Al mq/kq	0,12	ppm
Silicon, Si mq/kq	0,09	ppm
CO_3	2	Meq/l
HCO_3	4	Meq/l
NaCl	2,7	%
SO_4	3,4	Meq/l

As can be seen from the results of the table, the waters of the river are also clogged with heavy metal ions.

Conclusion

As a result, it was concluded that the maximum use of technogenic industrial waste is the main direction of resource saving in the production of building materials. The use of waste from the mining, metallurgical and energy industries can reduce the need for natural materials by 20-40%. Secondary raw materials of non-ferrous metallurgy are a large reserve for the production of building materials. Studies have shown the possibility of making brick products from a mixture of waste products such as red bauxite mud, bleaching clay used in the purification of edible oils, and household waste. Based on the generalization of voluminous literary and scientific material, it can be concluded that red mud can be used as an additive that increases the mechanical strength of concrete. The use of solid waste from alumina production will expand the range of concretes, practically without changing existing technologies for the manufacture of small-piece wall materials, and will also contribute to the environmental improvement of the environment through the disposal of harmful substances contained in man-made products. The considered aspects of the processing of non-ferrous metallurgy solid waste showed that they can serve as a raw material for obtaining a number of promising materials, in particular, effective catalysts, since it contained iron and aluminum, which are the main components of catalysts.

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MODELING OF THE HYDROMECHANICAL PROCESSES OF SLURRY FORMATION AND MOVEMENT DURING HYDROMINING OF ZEOLITE-SMECTITE TUFFS

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Annotation

The materials of theoretical and practical researches are aimed at improvement of mathematical models of individual technological operations of the technology of underground development of zeolite-smectite tuff deposits of the Rivne-Volyn region by the hydraulic well method, taking into account the dominant factors of the hydraulic mining process.

The subject of the research is the parameters of hydrodynamic erosion of zeolite-smectite tuffs, the movement of the slurry in the conditions of the mining chamber and the transportation of the mineral. The work uses a comprehensive research method, which includes a system analysis and generalization of the experience of borehole hydromining, physical modeling of hydrodynamic processes, applied and bench research using industrial samples of technological equipment, as well as a mathematical modeling method - to establish dependencies between parameters well hydraulic mining.

During the research and development of hydrodynamic mathematical models, the method of analyzing the processes of pulp flow over a conical surface was used, in which the stationary parameters of the flow process were determined and the influence of various factors on the uneven movement of slurry was investigated. In the proposed mathematical models, the dynamic characteristics of the process are sufficiently fully considered, and the parameters of the roughness of the solid boundary of the flow are also taken into account.

On the basis of the conducted research, recommendations were developed for the use of well hydrotechnology depending on the state of the deposit and the composition of the rock, the method of selecting the parameters of the hydro-fracturing process and self-draining hydraulic transportation of zeolite-smectite tuffs along the bottom of the extraction chamber was investigated and improved. Proposed technological solutions for the installation of round-shaped mining chambers in thick layers of rock.

Introduction

Interest in volcanic tuffs, which is connected with the discovery of deposits of zeolite tuffs, which have valuable sorption, cation exchange and other properties, has been growing significantly in recent years. The ambiguity in the characteristics and diversity of volcanic tuffs (more than 40 varieties have been discovered in the world) is primarily related to the conditions of formation and the age of a particular deposit. Tuffs from different deposits may differ in color, strength, and physical and chemical properties. At the same time, for the same deposit, the difference in the composition of tuffs is manifested depending on the depth or location. To a large extent, this is the reason for the insufficient exploration and lack of reliable analytical and technological data on tuff slurry of some deposits [1, 2]. The estimated resources of such zeolite-containing volcanic tuffs in the Rivne region amount to hundreds of millions of tons, that is, they are practically inexhaustible.

The analysis of tuff deposits explored in the Rivne-Volyn region and their wide economic purpose encourage the rapid development of deposits of these minerals, and the impossibility of an surface method of mining, due to being confined to a nature reserve zone, the presence of highly productive agricultural land and excessive irrigation of the territory, requires the search for alternative mining methods. The increase in the depth of tuff in the northern part of the region, the presence of a reliable solid roof in the form of basalt layers, significant water absorption of the rock and the ability to self-destruct under prolonged exposure to moisture, favorable hydrogeological conditions, are indisputable arguments and grounds for using the underground method of developing zeolite-smectite tuffs in Rivne-Volyn region by the method of well hydrotechnology [3-7].

Smectite tuffs with a content of smectite minerals of more than 50%, which have a swelling crystal lattice and, in most cases, a high surface energy, which causes the active interaction of minerals with water, which can be absorbed or released through interlaminar spaces are suitable for borehole hydraulic production in terms of physical and mechanical properties. At the same time, minerals increase or decrease in volume, and become plastic when wet. The recommended smectite for hydraulic mining is montmorillonite, which can increase in volume by 20 times due to the absorption of water. During dehydration, the volume of the mineral decreases sharply.

As for zeolite tuffs, they are solid inorganic compounds of a frame structure that are strongly cemented, do not undergo hydraulic erosion and are not subject to hydromining.

The main studies of parameters of borehole hydrotechnology for tuff extraction were carried out at the Rafalivsky deposit, which is located in the Volodymyretsky district of the Rivne region and partially in the Manevytskyi district of the Volyn region.

The area of the field is 6,4 km^2, including the area of previous exploration - 1,2 km^2.

Administratively, the research area, which has the thickest layers of zeolite-smectite tuffs, is located within the Volyn and Rivne regions of Ukraine.

Taking into account the significant dependence of the chemical composition of tuffs on the deposit and its significant difference within one deposit, and the lack of detailed research in this direction at this time, it can be predicted that in the process of mining operations, the rational limits of the application of the development method in relation to the varieties of tuffs will be determined. Improved methods of its extraction and formulated general principles of complex processing.

Taking into account that the creation of a general model of well hydraulic production technology is practically impossible due to methodological and technological difficulties, studies were conducted for individual technological operations.

Mineral erosion

The main element of the system – the erosion of the mineral includes the reflection of the rock with a hydromonitor water jet and the supply of the pulp to the area of action of the suction nozzle or to the output product. The movement of liquid in a stream is characterized by the movement of water particles in the absence of solid boundaries of the channel. During the movement of a jet, when several liquids of different densities are mixed, as well as in multiphase, when the substance of the jet and the substance of the medium are in different physical states (gaseous or droplet), and sometimes with an admixture of solid particles in the boundary layer of the jet, phenomena occur are so complex that at the present stage there are no reliable methods of their analytical determination.

Determination of the features of the hydrodynamic erosion process was carried out under natural conditions at the basalt quarry of the village Ivanchi, Rivne Oblast, where overlying rocks were removed from the test site to expose the mineral. According to the data of geological studies, tuffs lie above the water saturation zone, therefore, in the studies, unflooded hydromonitor streams of medium (1MPa-4MPa) pressure were considered. In the calculation of the interaction of the stream with the rock massif, a scheme with a one-way output was used, which most fully corresponds to the technology of formation processing both from top to bottom and from bottom to top.

Erosion of the mineral was carried out layer by layer at a ledge height of 1-35 cm with its movement by the stream to a limit distance equal to the radius of erosion. The speed of movement of the shock nozzle of the hydromonitor in the sector of the blowout varied from 0,3 to 2,4 m/s. Breakout and transport of the rock represent a single process and were carried out by the sequential action of the jet on the constantly moving outcrop.

During the destruction of zeolite-smectite volcanic tuffs under the influence of the pulsating action of the jet, the connection between individual particles of the rock was broken. As a result of filtering part of the water into the pores, their moistening and wetting took place, which led to a cohesive force between the particles. In addition, in an unflooded blowout, the mass of stream water accumulated in the recess opened it up and, as a result, tensions arose in the massif, which contributed to the appearance of cracks and the detachment of individual pieces of rock.

Experimental data on the radius of erosion of zeolite-smectite tuffs by the jet of the hydromonitor are given in the table 1.

The experiment established that erosion of tuffs by jets of a larger diameter leads to an increase in the radius of erosion, and with an increase in the pressure of the working agent, the productivity of erosion increases significantly.

Table 1

Water pressure in the nozzle	No. of the experiment	Nozzle diameter d_0, mm				
		15	20	25	30	35

H_0=1 MPa	1	The value of the erosion radius *R*, m	2,2	3,3	4,25	6,0	8,1
	2		2,25	3,2	4,3	6,1	8,1
	3		2,2	3,4	4,5	6,2	8,3
	Average		2,22	3,30	4,35	6,10	8,17
H_0=1,6 MPa	1		3,5	4,4	5,5	7,4	9,5
	2		3,6	4,55	5,6	7,65	9,7
	3		3,5	4,5	5,6	7,5	9,7
	Average		3,53	4,48	5,57	7,52	9,63
H_0=2,2 MPa	1		5,1	6,0	7,3	9,1	11,5
	2		5,3	6,15	7,45	9,2	11,6
	3		5,1	6,05	7,4	9,15	10,9
	Average		5,17	6,07	7,38	9,15	11,33

The dependence of the radius of erosion on the pressure of the working agent and the diameter of the nozzle for zeolite-smectite tuffs of the Rafal quarry is approximated by the following equation.

$$R(d_0, H_0) = 0{,}9e^{0{,}064 \cdot d_0} + 2{,}5 \cdot H_0 - 2{,}5 \qquad (1)$$

The maximum relative error of the calculation of the rock erosion radius according to the established dependence was 9,07%.

The productivity of tuff erosion, depending on the pressure and diameter of the hydromonitor nozzle, is approximated by the following relationship:

$$\Pi_p(d_0, H_0) = 0{,}07\mathrm{H}_0 \cdot e^{148 \cdot d_0} + 3{,}3 \cdot H_0 - 2{,}8 \qquad (2)$$

The maximum error when calculating the erosion performance was 12,3%.

When deriving analytical dependencies based on experimental data, which are complex functions of two variables for families of curves, an approximation dependency of a certain type was constructed as a function of one variable for each curve. Then, based on the values of the coefficients in the equations of these curves, graphic and approximation dependencies were built, which are functions of the second variable. Replacing the coefficients of the first approximation dependence with the equations of the second variable made it possible to obtain a function of two variables.

Dependence between the parameters

The process of hydraulic transportation of the pulp to the automated borehole hydromonitor or output products is a separate element of the system, therefore the reliability of the operation of each link determines the efficiency of the entire technological complex. Knowing the nature and basic laws of this element will allow you to choose the optimal conditions for transporting the hydraulic mixture.

It should be noted one more important circumstance: the research of hydraulic transportation in related industries was carried out, as a rule, with the constant flow of the working fluid, while the hydraulic transportation of the slurry in these conditions took place with a variable flow of water. In addition, all known studies were carried out during the transportation of material that does not have an initial speed (it lies motionless on the chamfer or on the bottom of the production), which is significantly different from the conditions of erosion and hydraulic transportation at the bottom of the chamber. Here, the mineral has a significant reserve of kinetic energy when it falls to the bottom of the chamber. With a certain flow rate of the working fluid and the slope of the bottom, the initial speed of movement of the hydraulic mixture can have a predominant effect on further transportation along the bottom of the chamber.

It is characteristic that most studies did not set the task of active intervention in the process of formation and preservation of the dynamics and kinematics of the movement of the slurry in order to obtain optimal conditions for self-flowing and forced hydraulic transportation. Solving the hydraulic transportation issues mainly came down to determining the transport capacity of the stream. This approach to the calculation of hydraulic transportation in the conditions of the technology of well hydraulic mining is unacceptable, since the ability of hydraulic transportation comes from the possibility of hydraulic fracturing.

The lack of analogues and the need for effective hydraulic transportation require the identification and establishment of the following dependencies: the influence of water consumption on the transport capacity of the stream; influence of the slope of the bottom of the chamber on the transport capacity of the flow; the effect of the roughness of the bottom of the chamber on the productivity of transportation; detection of the impact of the initial energy of particles on technological losses.

As a basis, for the study of the process of interaction between the destroyed tuff and the flow of liquid, the theoretical dependences established by many researchers and given in the literature [8-12] were used.

When the stream acts on the destroyed rock, particles of minerals are carried out of the zone of its influence and a trench is formed. What is more, the removed particles form a stream not only along the course of the jet, but also from the sides of the trench. The calculation of the process of rock washing in a submerged indentation is reduced to the determination of the geometric dimensions of the stream and the trench and the time of formation of the pit.

When the nozzle is immersed in the rock, erosion occurs against the foundation of the pit, that is, the eroded rock is carried away and stacked behind the upper edge of the pit. As the nozzle deepens, the length of the trench becomes shorter, and when the nozzle is lowered below a certain depth h_{cr} the process of pit formation stops and the lifting and movement of the rock mass begins with the formation of diffusion zone. Further immersion of the nozzle leads to the creation of a stationary volume of rock under the diffusion zone.

In the diffusion zone, the rock moves along a closed trajectory. At first, it, captured by the stream of water, moves horizontally. Then, having lost energy, it turns vertically upwards. The rock raised above the surface of the flow is pushed to the nozzle and is again included in the movement.

Research of the diffusion zone made it possible to establish the dependence between the parameters of the stream (r_0 and u_0) and the type of rock, the characteristics of which are the non-eroding speed and the dimensions of the erosion and diffusion zones. These dependencies have the following form

$$\frac{u_0}{u_{\text{нер}}} = \frac{0{,}0004}{r_0^2}[(a' - h_1) + 4K(h_1 + h_2)]^2 \tag{3}$$

$$\frac{u_0}{u_{\text{нер}}} = \frac{0{,}0064}{r_0^2}K^2(h_1 + h_2)^2\left[15\left(\frac{a'-h_1}{a'+h_2}\right)^2 - 1\right] \tag{4}$$

$$\frac{u_0}{u_{\text{нер}}} = \frac{0{,}008}{r_0^2}K^2(a' + h_1)^2\left[5\left(\frac{h_1+h_2}{a'+h_2}\right)^2 - 1\right] \tag{5}$$

where h_1 - is the height of the suspension zone above the surface; h_2 - depth of the suspension zone; K - is the average consistency of the pulp in the diffusion zone, which is defined as the ratio of the volume of the rock in its normal state to the volume of the pulp; r_0 - nozzle radius; a' - is the distance from the nozzle to the soil surface.

The width of the diffusion zone b is expressed in terms of h_1 and h_2 and is determined by the dependence b=1,3(h_1+h_2)–7.

Gravity hydraulic transport is possible only in the presence of a certain slope, and the pressure flow of liquid creates a hydraulic pressure gradient, as a result of which the rock mass moves with water.

At rest, stratification of the slurry occurs, and the rate of sedimentation mainly depends on the size and shape of the particles, their mineral composition. The presence of clay particles, as well as additives of surface-active substances, increase the stability of the slurry.

Depending on the hydraulic size of the transported particles, the critical speed of the hydraulic mixture is determined. When $u_s > u_m$ a jump-like movement of particles is observed, when $u_s > 2u_m$ the movement of the solid occurs in a suspended state, when $u_s > (3\text{-}5)u_m$ solid deposition in the flow is not observed. The process of movement of a hydraulic mixture with pieces of rock is very complex, and its consideration begins with a simple case - the movement of individual pieces in an open turbulent flow of liquid. At the same time, it is important to determine the conditions of friction of the pieces against the solid boundaries of the flow, the speed of contact of different samples, and the relative speed of their movement in the fluid flow.

By the value of the contact speed, the conditions of the hydromechanical action of the flow on the tuff pieces at the time of the start of translational movement are judged. The relative speed of movement of solid samples in the liquid flow is the most important kinematic characteristic of the movement of the slurry, thanks to which the conditions of interaction of the liquid and solid bodies are determined. During gravitational transport of tuffs, the speed of contact and the relative speed of movement of pieces in the fluid flow largely depend on the value of the friction coefficient.

For a finely dispersed slurry at a flow rate $u_s > u_0$, the separation of small particles from the lower wall of the flow is observed; with $u_s > 2u_0$ for a coarsely dispersed slurry, intermittent weighing of particles during transportation is practically completely ensured. At low flow saturations, it is enough to transport a hydraulic mixture with large pieces of rock so that the flow speed exceeds the speed of touching the pieces by 25-40%.

The productivity of transportation for all possible schemes is determined by the water consumption through the nozzle of the hydromonitor and the specific water consumption for washing 1 m^3 (or 1 ton) of rock.

The specific consumption of water for flushing is determined experimentally for each rock and depends significantly on the state of the pit.

Through the parameters of the hydromonitor, the performance is expressed by formula 2.

During borehole hydraulic mining of zeolite-smectite tuffs, pulp formation is carried out by a rotating hydraulic monitor. The hydromonitor erodes the formation by rotating with a certain angular velocity around the vertical axis of symmetry of the extraction chamber. Thus, the dimensions of the extraction chamber and the characteristics of the pulp flow process in it are determined by the performance and rotation frequency of the hydromonitor.

Alternatives to the choice of borehole hydrotechnology

At the preliminary stage, the choice is made within the framework of an increased technical and economic analysis. One or another method of hydraulic mining can be established based on the analysis of the indicators of the base deposit. At the same time, the choice is greatly influenced by the hydrogeological conditions of the deposit and the value of the mineral.

With regard to the development of powerful fields, when the time for working out the chamber is much higher than the limit value, an alternative is the system with the attachment of the cleaning space.

Mixing of rocks due to the structural design of the bottom of the extraction chambers occurs in systems in which hydraulic transport, as their element, within the chamber occurs by gravity. At the same time, the capacity of the system is determined by one unit of borehole hydraulic mining. Solving the problems of the completeness and quality of extraction makes sense only in the case when the underlying rocks are subject to hydromonitoring destruction, with the exception of systems with storage, the design of the bottom in which is carried out with the help of drilling and blasting.

The conducted studies are limited to the maximum exposure span of the roof of the extraction chambers L_{np}, in which during the period of time the chamber is fully worked out, there is no mixing of the superimposed rocks on one side, and natural phenomena associated, for example, with the removal of silt, as a result of which the chamber is blocked - on another side. System parameter M characterizes the depth of development of the underlying rocks at the value of the erosion radius R_{ni} and the limit span of the exposure of the roof of the extraction chamber L_{npi}.

The surface of reliable hydraulic transportation is characterized by the radius of curvature L_{ki}, the value of which is for discrete intervals $L_{npi}...L_{np2}$; $L_{np2}...L_{np1}$; $L_{np1}...0$ is permanent. With an increase in the parameters of the depth development of deposits the values of L_{np} and M are decreasing.

In general, the volume of mixed underlying rocks is determined by the formula

$$V_p = \pi \int_0^M [f(i)]^2 \, di \tag{6}$$

where i - is the current parameter of the transportation surface.

For engineering calculation methods, a simplified formula for determining V_p is recommended

$$V_p = \frac{\pi \cdot L_{npi}^2 \cdot M_i}{12} \tag{7}$$

The structural unit of the deposits site, by which it is possible to estimate the coefficients of quantity, quality and extraction from the subsoil (K_{kil}, $K_я$ and $K_н$), is a rectangle ABCD (Fig. 1), which includes two worked out extraction chambers in the first and second stages, and the lost volume of mineral that remained between the contours of the chambers (shaded in the figure).

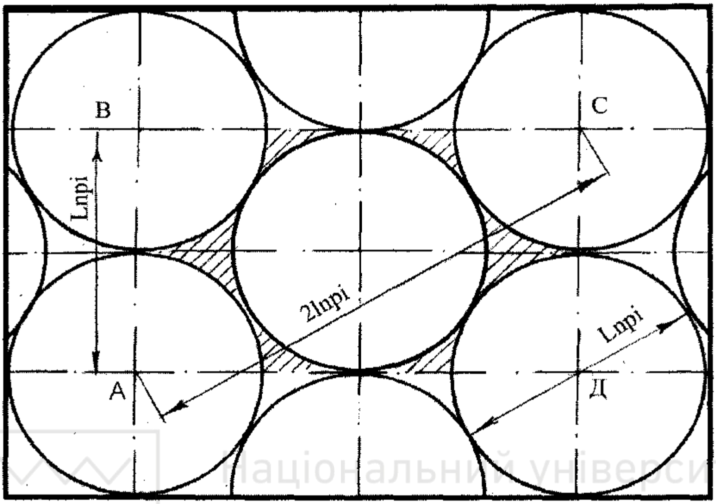

Fig. 1. The scheme for calculating the coefficients K_{kil}, $K_{я}$, $K_{н}$ of circular chambers

The coefficient of the amount of extraction for systems in which the bottom of the chamber is structurally made in the underlying rocks expresses the ratio of the mined mineral together with the rock mixed with it to the amount of balance reserves paid off during extraction.

The amount of mined mineral together with mixed underlying rocks (8) can be set as the sum of the volumes of the chamber made in the mineral with capacity m_i diameter L_{npi}, as well as mixed underlying rocks

$$V_k = \frac{\pi \cdot \mathbf{L}_{\text{пpi}}^2}{4} m_1 \tag{8}$$

The amount of balance reserves paid off during mining is defined as the sum of the volumes: the chamber made in the mineral (V_k), that falls on the extracting chamber, for the case of inter-chamber mineral that are not subject to mining according to economic criteria.

The coefficient of change in quality is defined as the ratio of the content of useful components in the mined mineral and in the balance reserves paid off.

The coefficient of extraction from the subsoil expresses the ratio of the amount of mineral extracted from the subsoil to the amount of mineral that is in the calculated balance reserves and can be found according to the relationship: $K_{н} = K_{kil} \cdot K_{я}$.

For systems in which the bottom of the chamber is structurally made of minerals (Figs. 2 and 3), the schemes for calculating indicators of completeness and quality of production are presented on the example of systems with an open cleaning space.

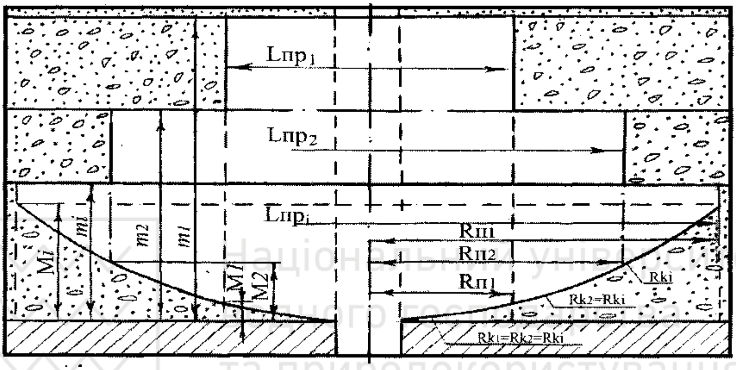

Fig. 2. The scheme for calculating the coefficients K_{kil}, $K_{я}$ and $K_{н}$ of circular chambers, the bottom of which is structurally made in the mineral itself, for development depths $H \leq 50$ m

Camera parameter M_i, which can be characterized as the depth of the graduation notch, is regulated by the factors discussed above.

Thus, in order to create reliable hydraulic transportation, it is necessary to leave some volume of mineral on the surface of the underlying rocks, limited from below by the surface of the underlying rocks and the side surface of the cylinder with a diameter set by the radius of erosion R_{ni} , or the limit span of exposure of the roof of the extraction chambers L_{npi}. The volume of mineral lost in the extraction chamber

$$V_n = \pi\left(\frac{\mathbf{L}^2_{\text{пpi}} \cdot \mathbf{M}_i}{4} - \int_0^{Mi} [f(i)]^2 \, di\right) \tag{9}$$

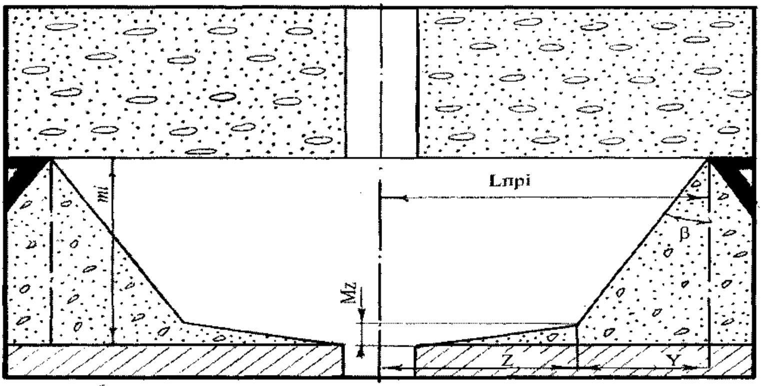

Fig. 3. The scheme for calculating the coefficients K_{kil}, $K_я$ and $K_н$ of circular chambers, the bottom of which is structurally made in mineral, for development depths H>50 m

For engineering calculation methods, it is recommended to use simplified analytical dependencies to determine the volumes of mineral extracted from the extraction chamber:

- deposit development depth up to 50 m

$$V_п = \mathbf{L}^2_{прі}(\mathbf{0,8}m - \mathbf{0,26M}_i) \tag{10}$$

- development depth over 50 m

$$V_п = 1{,}6L_{прі}m(0{,}5L_{прі} - m\tan\beta) - 0{,}54M_z(L_{прі} - 2m\tan\beta)^2. \tag{11}$$

Dependencies, which can be used to determine K_{kil}, $K_я$ and $K_н$ provided that the bottom of the mining chamber is structurally made in a mineral, are as follows:

- deposit development depth up to 50 m

$$K_{kil} = \frac{\mathbf{L}^2_{пр}(\mathbf{0,8}m + \mathbf{0,54M}_i)}{\mathbf{0,8L}^2_{пр}m + m\left[\mathbf{0,87}(\mathbf{L}_{пр} + x)^2 + \mathbf{0,78L}^2_{\mathbf{пр}}\right]},\ K_н = K_{kil}; \tag{12}$$

- development depth over 50 m

$$K_{kil} = 1 \cdot \frac{6m(0{,}5L_{пр} - m\tan\beta)}{1} \cdot 6m(0{,}5L_{пр} + x) -$$
$$\frac{0{,}54M_i(L_{пр} - 2m\tan\beta)^2}{1} \cdot 6m(0{,}5L_{пр} + x), \quad K_н = K_{kil} \tag{13}$$

Coefficient $K_я$ we take equal to 1 for both cases.

Calculation of extraction chambers

After extracting the mineral, the massif, which was subjected to artificial irrigation, becomes unstable. It follows from this that a correctly constructed scheme for calculating the mechanical behavior of the roof of the extraction chamber must take into account both the time factor and the change in the conditions of the laying of underground structures - ceilings and the target. The first condition is ensured by linear extrapolation in time of modeling results on equivalent materials. Satisfiability of the second condition is achieved by adjusting the modeling results with theoretical calculations that allow taking into account the quantitative and qualitative change in the laying conditions. The calculation is based on the condition of equilibrium of external and internal forces in the roof of the extraction chamber in a steady state. The mechanical behavior of the massif under technological influence can be formally modeled by the state of the ceiling and wholes, as the main bearing elements.

The common goal inherent in mining equipment is to bring the mineral to a mobile state at the place of occurrence with the help of a working agent fed into the chamber, limited by the scope of the problems to be solved regarding the processes of clean extraction.

The existing designs of borehole hydraulic monitors allow to arrange the circuit of the chamber only with a circular cross section. Mining hydraulic monitors and units of borehole hydraulic mining allow mining of minerals by sectors.

For example, if the chamber is formed by one well hydraulic mining unit, then its cross-section will have the shape of a circle (Fig. 4).

The use of borehole hydraulic production systems for testing and development of a rock layer is theoretically possible up to the depths at which the amount of rock pressure becomes equal to the compressive strength of the rock massif

$$H \le H_{гр} = \frac{\sigma_{ст} \cdot K_ф}{\gamma} \tag{14}$$

where $H_{гр}$ - is the limit depth of system application; $\sigma_{ст}$ - compressive strength limit of rocks; γ - rock density; $K_ф$ - coefficient of mineral shape: for ribbon $K_ф$ =1, for star-shaped $K_ф$=0,7.

With the average values of the compressive strength limit of rocks $\sigma_{ст}$=22,5·10^{5}Pa and density 2,08·10^4 t/m^3, the critical depth of application of borehole hydraulic production systems with left ribbon mineral will be 108 m, systems with star-shaped mineral - 76 m.

As a result of the mathematical analysis, the relationships between the limit span of the roof and the depth of development were established

$$L_{пр}=471 \cdot H^{-0,76}. \qquad (15)$$

The calculated values of stability of the span of the roof of the extraction chambers for the limit case are in good agreement with the modeling results.

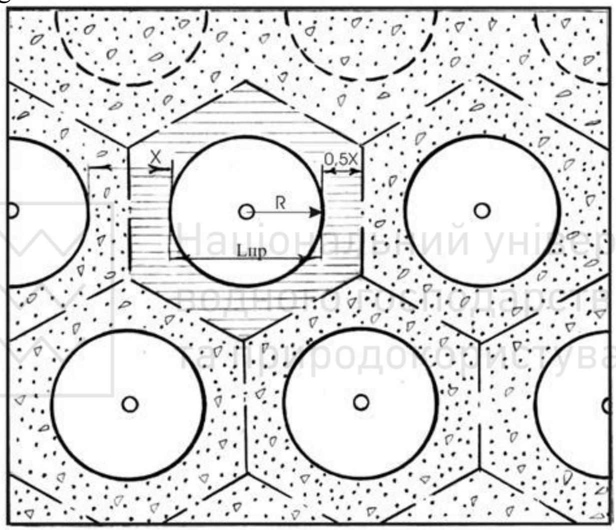

Fig. 4. Scheme for calculating parameters of extraction chambers of round shape and inter-chamber mineral without further loading of extraction space

In figure 5 shows the three-stage sequence of working out the mineral in the chamber for stable overlying rocks from the bottom to the top within the capacity of the formation.

According to its technological essence, the primary purpose of the mineral is to perceive the load from the overlying rocks. So, in a mechanical sense, the mineral material works on compression, that is, in the most favorable mode from the point of view of stability. However, the existence of free surfaces during uniaxial compression creates prerequisites for the occurrence of shaking tension along the sliding planes, which will be accepted as a criterion for the destruction of the mineral material. This concept is the basis of the theory of marginal equilibrium. The theory makes it possible to uniquely solve the system of equilibrium equations of the environment by including the limit state condition.

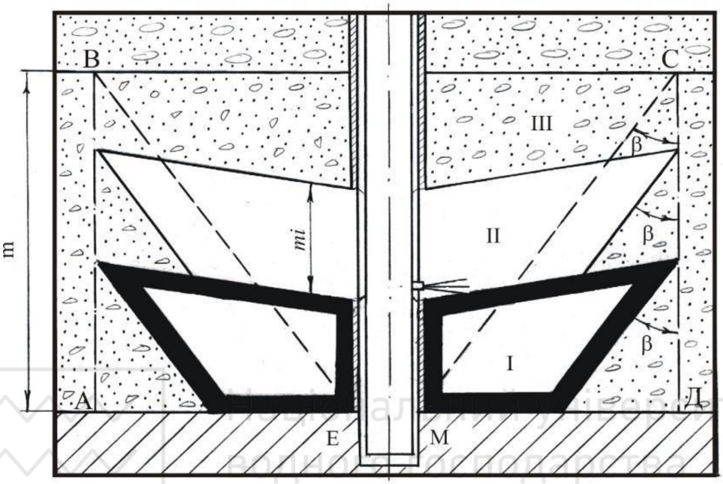

Fig. 5. The proposed technology of extracting a mineral of high capacity layer by layer from bottom to top: I, II, III – stages of extraction, respectively

In the preliminary approximation, we will consider the walls of the mineral to be vertical, along which there is no load, and the bursting pressure is created exclusively due to the cohesive forces of the rocks of the massif.

The maximum possible depth of formation of wholes with vertical walls with a height of $X_ц$ from the expression for active expansion

$$H_{пр} = \frac{\theta}{\lambda}\left(\frac{1+sin\varphi}{1-sin\varphi}\right) - X_ц \tag{16}$$

The change in the mechanical properties of the array over time is carried out through the environment parameter $\theta = C/tg\varphi$, in the formation of which φ and C participate.

On this basis, the dependence represented by the parameter θ on time t is recommended for use

$$\theta_t = 110{,}5 - 19t. \tag{17}$$

From formula (15), it is possible to estimate the degree of participation in the formation of the stability of the array of factors such as time and depth of testing (development). At the same time, a reserve of stability of 1 hour is equivalent to a decrease in depth by 19 m. Practically, this means that the previously performed calculations for stable parameters correspond to the initial moment of the camera's existence.

Taking into account the dependence of the θ indicator of the rocks on the angle of inclination of the walls of the target and to ensure stability for the required time at a certain depth (in the absence of other measures to strengthen the targets or improve their conditions), it is recommended to form the angle of the target's slope with the value

$$\beta = \frac{90\varphi\ \cdot}{\pi} \cdot \ln\ln\left[\frac{\gamma \cdot H}{\theta_т}\left(\frac{1 - sin\varphi}{1 + sin\varphi}\right)\right]. \qquad (18)$$

At depths of more than 50 m, the volumes of the strengthening prism may be significant, which will call into question the feasibility of using well hydraulic production systems.

The shape of the extraction chambers of the same system, which are formed at different depths, can be represented by the figure of ABCD at $H \leq 50$ m and the figure of BCME at $H > 50$ m (Fig. 5).

The size of AE strengthens the prism and at $\beta = 60^{\circ}$ and $m = 10$ m will be 20 m, that is, it will exceed the limit span of the roof $L_{пр}$, which will not allow it to construct the chamber of the required dimensions.

In this regard, it is proposed to extract the mineral within the contours of the chamber in several stages with the division of the capacity of the bed of rock m into a certain number of segments with a rational height.

At the first stage, a part of the mineral with a capacity of m_i in the formation of which with the formation of a strengthening prism at an angle β. After the mineral is mined, the produced space is laid with a hardening material. The second and third stages repeat the operations of the first, with the exception of bookmarking at the third stage, which may not be performed.

Thus, working out extraction chambers with the proposed technology allows to significantly increase production from one well and reduce losses of minerals.

Mathematical model of the process of movement of slurry

Considering the fact that volcanic tuffs in the Rivne-Volyn region lie in layers with a thickness of several meters to 100 or more meters, in the process of erosion, depending on the area of work, mining chambers with the arrangement of the bottom can be used both in the mineral itself and in underlying rocks. The bottom of the extraction chamber is a conical surface, in the center of which there is a receiving box with a hydraulic elevator.

The diameter and angle of inclination of the bottom of the extraction chamber are determined by the technological parameters of the well hydraulic production and changes during the process. The roughness of the bottom depends on the type of rock and the nature of its destruction.

A small number of works [13-15] are dedicated to the development of hydrodynamic models of pulp flow over a conical surface, in which, mainly, stationary parameters of the flow process are determined and the influence of various factors on the non-uniform movement of the fluid mixture is investigated. However, these works do not sufficiently consider the dynamic characteristics of the process, and also do not take into account the parameters of the roughness of the solid boundary of the flow.

To confirm the reliability of experimental and natural studies, theoretical studies of the process of erosion and movement of the pulp from the bottom of the extraction chamber to the suction nozzle of the hydraulic elevator were conducted. The theoretical dependences developed by professors Z.R. Malanchuk, O.G. Gomon, and E.I. Chernya are taken as a basis [16-19].

To analyze the process of pulp flow through the bottom of the extraction chamber, we will use the model of the movement of a homogeneous liquid in a thin layer, assuming that the velocity is the same throughout the thickness of the layer, and the presence of friction between the liquid and the bottom is taken into account using empirical formulas. Such a model is relatively easy to analyze and, under certain assumptions, allows an analytical solution [20].

To describe the process of the movement of the pulp layer along the conical surface, we will choose a spherical coordinate system. Align the $0z$ axis of the spherical coordinate system with the $0z\theta\psi$ axis of symmetry of the conical surface and direct it vertically upwards (Fig. 6).

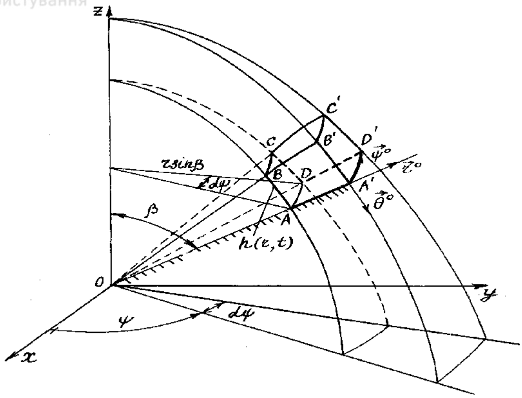

Fig. 6. Coordinate system and fluid flow element

Denote the angle of the half cut of the bottom of the extraction chamber by β. We will assume that the liquid flows over the surface in a thin layer, for the thickness of which, measured along the internal normal to the conical surface, the condition $h/r<<1$ is fulfilled. In this case, the thickness of the layer, measured along the normal to the conical surface, and the thickness, measured along the coordinate line θ along the arc AB will differ slightly. Therefore, the linear size measured from the surface of the cone $\theta=\beta$ along the arc of the meridian AB can be considered as the thickness of the layer $h(r, \psi, t)$.

As an elementary volume to which we will apply the laws of conservation, we will choose an element $ABCDA'B'C'D'$, bounded by spherical surfaces of radii r and $r+dr$, surfaces $\psi=const$ and $\psi+d\psi$=const, as well as the section of the conical surface $\theta=\beta ADD'A'$ and the area of the free surface $BCC'B'$.

At the same time, the area of faces $ABCD$ of the element will be equal to: $r sin\beta d\psi \boldsymbol{h}$, and faces $ABB'A' - dr\cdot h$. The volume of the element in this case will be: $r\cdot sin\beta\cdot h\cdot dr\cdot d\psi$.

Accordingly, the flow through faces normal to $\vec{r}^{\,0}$, equal to

$$-\frac{d}{dr}(\rho\cdot V_r\cdot r\cdot \boldsymbol{h}) sin\psi\, d\psi dr \tag{19}$$

and through faces normal to $\vec{\psi}^{\,0}$

$$-\frac{d}{d\psi}(\rho V_\psi \boldsymbol{h})drd\psi \tag{20}$$

where V_r - radial component of velocity; V_ψ - circular component of speed; ρ - is the density of the liquid.

Since in this task there is no inflow of matter through a free surface, then, according to studies [21], the vertical component of the velocity V_θ in the layer can be neglected. In this case, the accumulation of matter in the element with the above volume per unit of time will be equal to

$$\rho r sin\beta \frac{d\boldsymbol{h}}{dt} drd\psi \tag{21}$$

The law of conservation of mass leads to an equation

$$r \cdot sin\beta \cdot \frac{d\boldsymbol{h}}{dt} + sin\beta \cdot \frac{d}{dr}(V_r \cdot r \cdot \boldsymbol{h}) + \frac{d}{d\psi}(V_\psi \cdot \boldsymbol{h}) = \mathbf{0} \tag{22}$$

In the case of axisymmetric flow ($V_\psi \equiv \mathbf{0}$), we have the equation

$$r\frac{d\boldsymbol{h}}{dt} + \frac{d}{dr}(V_r r\boldsymbol{h}) = \mathbf{0} \tag{23}$$

Instead of the variable r, we will enter the variable x calculated from the initial section of the layer: u=-V_r ; x=l–r. At the same time, instead of equations (22) and (23), we will have

$$\frac{d\boldsymbol{h}}{dt} + \frac{\mathbf{1}}{l-x}\frac{d}{dx}[u\boldsymbol{h}(l-x)] + \frac{V_\psi \boldsymbol{h}}{(l-x)\sin\beta} = \mathbf{0} \tag{24}$$

$$\frac{d\boldsymbol{h}}{dt} + \frac{\mathbf{1}}{l-x}\frac{d}{dx}[u\boldsymbol{h}(l-x)] = \mathbf{0} \tag{25}$$

where l - is the total length forming the bottom of the extraction chamber.

Since the layer is thin, when considering the momentum equation, the acceleration of particles along the normal to the bottom of the flow and the change in the mass force along the thickness of the layer can be neglected [21]. In this case, the equation of motion in the projection on the axis $\vec{\theta}^{\mathbf{0}}$ will take the form

$$\frac{dp}{d\theta} = \rho g r \sin\beta \tag{26}$$

After integrating this equation by θ within the layer and taking into account that above the free surface y=h the pressure is constant and equal to the atmospheric pressure p=p_a=$const$, finally the law of pressure distribution in the layer can be written in the form

$$p = p_a + \rho g \sin\beta\,(h - y) \tag{27}$$

where - is a linear coordinate in the layer counted from the base along an arc of radius r.

Denoting through τ_0 the value of the tangential pressure at the bottom of the layer, for the equation of impulses in the projection on the direction $\vec{r}^{\,0}{}_0$ for axisymmetric flow, we get

$$\frac{d}{dt}(\rho h V_r) + \frac{1}{r}\frac{d}{dr}(\rho V_r^2 h r) = -\rho g \sin\beta\, h \frac{dh}{dr} - \tau_0 - \rho g \cos\beta\, h \tag{28}$$

Combining this equation with the continuity equation (23) and moving to the variables x and u, we obtain the momentum equation in the form

$$\frac{du}{dt} + u\frac{dn}{dx} + g\sin\beta\frac{dh}{dx} = -\frac{\tau_0}{\rho h} + g\cos\beta \tag{29}$$

which, together with (25), forms a system of equations for the unsteady flow of the pulp layer over the conical surface.

Taking into account the peculiarities of the bottom of the extraction chamber, which can consist of rocks of different roughness, to determine the frictional pressure τ_0 at the bottom of the extraction chamber, we apply the well-known Chézy formula

$$\tau_0 = g\frac{\rho u^2}{C^2} \tag{30}$$

where C is the Chézy coefficient, the value of which is determined depending on the material and the relative roughness of the bottom of the extraction chamber.

Model of stationary pulp flow

For the stationary flow of destroyed tuff along the bottom of the extraction chamber, the theoretical model presented in the work of the authors O.H. Gomon and Z. R. Malanchuk is most suitable. [22, 23].

If the flow parameters at the beginning forming the bottom of the extraction chamber are stationary, then a stationary flow is realized on the conical surface, which, due to (25) and (29), satisfies the system of equations

$$\frac{d}{dx}[uh(l - x)] = 0$$

$$u\frac{du}{dx}+g\sin\beta\frac{dh}{dx}=-\frac{\tau_0}{\rho h}+g\cos\beta \qquad (31)$$

$$uh(l-x)=q$$

where the value q is determined by the parameters of the mineral erosion process by the hydromonitor.

The system of equations (31) can be solved by obtaining the following equations for u and for h :

$$\frac{du}{dx}=\frac{\left[g\cos\beta-\frac{gn^2}{q^m}u^{2+m}(l-x)^m-\frac{qg\sin\beta}{u(l-x)^2}\right]u^2(l-x)}{u^3(l-x)-qg\sin\beta} \qquad (32)$$

$$\frac{dh}{dx}=\frac{q\cos\beta h^3(l-x)^2-\frac{gn^2}{h^{m-1}}q^2-\frac{q^2h}{l-x}}{g\sin\beta\, h^3(l-x)^2-q^2} \qquad (33)$$

Differential equations (32) and (33) are equivalent, and any of them together with (34) determines the distribution of flow velocities and heights along the forming bottom of the extraction chamber. Any of these equations can be solved by numerical methods if the initial data u_0 and h_0 at x=0 are given. We also note that the integral curves of equations of the type (32) and (33) have been sufficiently fully investigated in hydraulics.

Converting the denominator of the last equation to zero means that the flow reaches a critical depth at a given location, at which the velocity reaches a critical value

$$h_{kp}=\left[\frac{q^2\sin\beta}{g(R-x\sin\beta)^2}\right]^{\frac{1}{3}} \qquad (34)$$

$$u_{kp}=\left[\frac{qg\sin^2\beta}{R-x\sin\beta}\right]^{\frac{1}{3}} \qquad (35)$$

Value $h_{н}$, in which x^{y}=0 we will call it the local normal depth. The value of $h_{н}$ satisfies the equation:

$$h_{\text{Н}}^{2+m}-\frac{q^2\sin^3\beta}{g\cos\beta\,(R-x\sin\beta)^3}h_{\text{Н}}^{m}-\frac{n^2q^2\sin^2\beta}{\cos\beta\,(R-x\sin\beta)^2}=0 \qquad (36)$$

The peculiarity of equation (36) is that it can be solved without determining the speed from the solution of equations (32) and (33).

Nonlinear model of unsteady pulp flow

The system of equations (25) and (29), taking into account (30), describes the unsteady movement of the pulp along the bottom of the extraction chamber:

$$\frac{du}{dt}+u\frac{du}{dx}+g\sin\beta\frac{dh}{dx}=-\frac{gn^2u^2}{h^m}+g\cos\beta \tag{37}$$

$$\frac{dh}{dt}+h\frac{du}{dx}+u\frac{dh}{dx}-\frac{uh\sin\beta}{R-x\sin\beta}=0 \tag{38}$$

The solution of system (37), (38) can be obtained numerically using the method of characteristics, if at some point in time $t=t_0$ the parameters forming the bottom of the extraction chamber are known $u^0(x)$ and $h^0(x)$, for example, from the solution of the stationary problem equations. At the same time, for a "calm" flow in the inlet and outlet sections, one of the functions $u(t)$ or $h(t)$, should be specified, and for a "turbulent" flow, both functions in the inlet section should be specified. Boundary conditions $u(t)$ and $h(t)$ can be arbitrary functions of time.

When applying the method of characteristics, it is necessary for system (37), (38) to find wave fronts and compatibility conditions on the surface of surface (x, t). At the same time, the characteristic directions x' on the plane (x, t) are determined from the condition that the determinant of the system is equal to zero

$$(u-x')\frac{du}{dx}+g\sin\beta\frac{dh}{dx}=A_1 \qquad h\frac{du}{dx}+(u-x')\frac{dh}{dx}=A_2 \tag{39}$$

where $A_1=g\cos\beta-\dfrac{gn^2u^2}{h^m}-\dfrac{du}{dt}$; $A_2=\dfrac{uh\sin\beta}{R-x\sin\beta}-\dfrac{dh}{dt}$.

From here we get $(u-x')^2=gh\sin\beta$, that is, there are two characteristic directions $x_1'=u+\sqrt{gh\sin\beta}$, $x_2'=u-\sqrt{gh\sin\beta}$, or, in other words, two wave fronts moving at speeds

$$\frac{dx_1}{dt}=u+c_0 \;\; i \;\; \frac{dx_2}{dt}=u-c_0 \tag{40}$$

where $c_0=\sqrt{gh\sin\beta}$ - own velocity of wave propagation.

The first wave front propagates downstream with velocity $u+c_0$, which is ahead of the current. The second wave front propagates downstream or upstream, depending on whether $u>c_0$ or $u<c_0$. If $u>c_0$ then the second front, just like the first, spreads downward and such a current is "turbulent". If $u<c_0$, then the second front spreads

upstream towards the first, and such a flow is called "tranquil". In a calm flow along the first front, disturbances are transmitted from the inlet section to the outlet section, and along the second front - vice versa. In a turbulent flow, disturbances are localized between the fronts and spread from the inlet section to the outlet section.

The trajectories of wave fronts in the plane (x, t) with velocities dx_1/dt and dx_2/dt will be called the first and second families of characteristics, respectively.

The characteristic ratios are based on the equality of the zero determinant

$$\begin{vmatrix} A_1 & g\sin\beta \\ A_2 & u-\dot{x} \end{vmatrix} = 0 \qquad (41)$$

For the first family, this ratio has the form

$$g\sin\beta\frac{dh}{dt} + c_0\frac{du}{dt} = B_1 \qquad (42)$$

and for the second family - the form

$$g\sin\beta\frac{dh}{dt} - c_0\frac{du}{dt} = B_2 \qquad (43)$$

where $B_{1,2} = \dfrac{\sin^2\beta\ uh}{R - x\sin\beta} \pm c_0\left(\dfrac{gn^2u^2}{h^m} - g\cos\beta\right)$.

The numerical procedure of the method of characteristics is constructed by replacing the differential relations (40), (42) and (43) with finite difference relations and solving the resulting algebra equations step by step. Thus, the method of characteristics makes it possible to build a nonlinear solution of a non-stationary problem with any necessary accuracy and, in particular, to find the dependence of the output parameters on the input parameters.

Dynamic model of pulp flow

To describe the process of pulp flow over a conical surface, flow models in the form of two liquid layers with different densities are known [24]. Similar models, based on averaging over a live section of hydrodynamic parameters, with one or another modification, are widely used in the hydraulics of open channels. However, during borehole hydraulic extraction of tuffs, the flow of pulp along the bottom of the extraction chamber must be described by a model of single-layer flow of a liquid of variable density, which changes as a result of particles of solid material falling to the bottom. At the same time, we believe that the deposited material does not form a mobile layer, as it accumulates in the pores, cracks and roughness of the bottom of the extraction chamber and refers to rock losses.

According to this model, the layer is a mobile pulp, from which, during its movement along the channel, solid rock particles continuously settle to the bottom of the stream. The concentration of rock particles in the upper layer changes continuously, so that its density is considered as a function of the longitudinal coordinate and time. Let us also assume that in the pulp layer, solid particles are transported along the forming channel without sliding.

The equation of laws of conservation of mass and momentum shall be written in a spherical system of coordinates, assuming that the layer of pulp is sufficiently thin. The equation of the law of conservation of mass will be written separately for the carrier liquid and for solid particles. The normal rate of solids deposition to the bottom surface is w.

If we consider only axisymmetric flows along the conical surface (V_ψ=0), then the equations of conservation of liquid and solid phases in the pulp layer will have the form

$$\frac{d}{dt}[(1-\varphi)\boldsymbol{h}] + \frac{\boldsymbol{1}}{r}\frac{d}{dr}[(1-\varphi)\boldsymbol{h}rv] = \boldsymbol{0} \tag{44}$$

$$\frac{d}{dt}(\varphi\boldsymbol{h}) + \frac{\boldsymbol{1}}{r}\frac{d}{dr}[\varphi r\boldsymbol{h}v] = -\varphi\mathbf{w} \tag{45}$$

$$\rho = \rho_l(1+Ar\varphi)\,,\; \rho_l = \rho_{\boldsymbol{0}}(1+Ar_l\sigma) \tag{46}$$

$$Ar = \frac{\rho_s - \rho_l}{\rho_l}\,,\; Ar_l = \frac{\rho_s - \rho_{\boldsymbol{0}}}{\rho_{\boldsymbol{0}}} \tag{47}$$

where h - is the layer thickness; v - layer velocity averaged over the live section; ρ - current pulp density; φ - volume fraction of the rock in the pulp; ρ_s - density of rock particles; ρ_l - is the density of the carrier mixture; σ - volume fraction of the rock in the carrier mixture; ρ_o - is the density of water.

Combining equations (44) and (45) and replacing parameters $r=l-x$ and $u=-v$, let's write the previous system in the form

$$\frac{d\boldsymbol{h}}{dt} + \frac{\boldsymbol{1}}{l-x}\frac{d}{dx}[(l-x)\boldsymbol{h}u] = -\varphi\mathbf{w} \tag{48}$$

$$\boldsymbol{h}\left(\frac{d\varphi}{dt} + u\frac{d\varphi}{dx}\right) = -\varphi(1-\varphi)\mathbf{w}\,. \tag{49}$$

Equation (49) is used to determine the current, averaged over the thickness of the layer, fate of the solid φ due to the sedimentation of the rock from it in the cracks of the surface of the bottom of the extraction chamber.

System (44), (45) also allows one to write down one general equation of the law of conservation of mass of the mixture in the upper layer:

$$\frac{d}{dt}(\rho \boldsymbol{h}) + \frac{\mathbf{1}}{l-x}\frac{d}{dx}(\rho u \boldsymbol{h} r) = -\varphi \mathbf{w} \rho_s \text{ . (50)}$$

Let's write the momentum equation for the pulp layer, considering it as a homogeneous mixture. At the same time, we will assume that there is hydrostatic pressure in the thickness of the layer, which is determined according to (50)

$$p = \rho_a + \rho_l g(\delta - y)\sin\beta \text{ ,} \quad (51)$$

and the thickness of the layer δ and the ordinate y are measured along the normal to the side surface of the extraction chamber. In the momentum equations, the frictional stress on the bottom τ_0 is taken into account and rolling force $g\cos\beta$

$$\frac{d}{dt}(\rho u \boldsymbol{h}) + \frac{\mathbf{1}}{r}\frac{d}{dr}(\rho u^2 \boldsymbol{h} r) = -\rho_l g \boldsymbol{h}\frac{d\boldsymbol{h}}{dx}\sin\beta - \frac{gn^2\rho u^2}{\boldsymbol{h}^{2y}} - g\rho \boldsymbol{h}\cos\beta - \varphi \mathbf{w} u \rho_s \quad (52)$$

Combining equation (52) with the continuity equation, we arrive at the following equation for single-layer pulp flow along the bottom of the extraction chamber:

$$\frac{du}{dt} + u\frac{du}{dx} = -\frac{\rho_l}{\rho} g \frac{d\boldsymbol{h}}{dx}\sin\beta - \frac{gn^2u^2}{\boldsymbol{h}^m} + g\cos\beta \quad (53)$$

To close the system of equations (50), (53), the particle sedimentation rate w must be specified in the function of the parameters sought.

For the stationary case, this system of equations has the form

$$\frac{d}{dx}[(l-x)\boldsymbol{h}u] = -\varphi \mathbf{w}(l-x) \quad (54)$$

$$\frac{d\varphi}{dx} = \frac{\varphi(\varphi - \mathbf{1})\mathbf{w}}{hu} \quad (55)$$

$$u\frac{du}{dx} = -\frac{g\sin\beta}{1 + Ar\varphi}\frac{d\boldsymbol{h}}{dx} - \frac{gn^2u^2}{\boldsymbol{h}^m} + g\cos\beta \quad (56)$$

Rock particles that fell from the pulp flow into rock cracks at the bottom of the extraction chamber constitute rock losses. The system of equations allows you to determine these losses depending on the parameters of the bottom of the extraction chamber and the characteristics of the pulping process. The mass of rock that falls out of the annular segment in width *dx* per unit of time is equal to

$$dM = 2\pi\varphi\rho_s \mathbf{w}(l - x)\sin\beta dx \tag{57}$$

Thus, the volume fraction of rock particles that fell out of the moving layer will be described by the following equation:

$$\frac{d\Pi}{dx} = \frac{2\pi\varphi \mathbf{w}(l - x)\sin\beta}{q_0(1 - \varphi)} \tag{58}$$

where $q_0=2\pi q\sin\beta$ - pulp productivity.

Solving the obtained equations relative to the derivatives, we will obtain the final system of equations for single-layer pulp flow, taking into account rock losses:

$$\frac{dh}{dx} = \frac{gh\cos\beta - \frac{gn^2u^2}{h^m} - \frac{hu^2\sin\beta}{R - x\sin\beta} + \varphi uw}{\frac{hg\sin\beta}{1 + Ar\varphi} - u^2} \tag{59}$$

$$\frac{du}{dx} = \frac{\frac{gn^2u^3}{h^{2y}} + \frac{ghu\sin^2\beta}{(1 + Ar\varphi)(R - x\sin\beta)} - \frac{\varphi wg\sin\beta}{(1 + Ar\varphi)} - ug\cos\beta}{\frac{gh\sin\beta}{(1 + Ar\varphi)} - u^2} \tag{60}$$

$$\frac{d\varphi}{dx} = \frac{\varphi(\varphi - 1)w}{hu} \tag{61}$$

$$\frac{d\Pi}{dx} = \frac{\varphi w(R - x\sin\beta)}{q(1 - \varphi)\sin\beta} \tag{62}$$

For the obtained equations, the inherent speed of wave propagation depends on the density and volume fraction of the rock in the pulp flow and is determined by the formula

$$u_c = \sqrt{\frac{gh\sin\beta}{1 + \varphi Ar}}.$$

The initial conditions for solving the Cauchy equation for the system (59)...(62) at the place where the pulp enters the bottom of the extraction chamber ($x=0$) are as follows $h=h_0$, $u=u_0$, $\varphi=\varphi_0$, where values are h_0 and u_0 are determined by the parameters and mode of operation of the hydromonitor, φ_0 is the concentration of the rock in the ore.

To solve the equations of the system (59)-(62) hydraulic size of rock particles is determined by the formula

$$w = w_0(1 - \varphi) \tag{63}$$

where w_0 - is the hydraulic particle size in an infinite liquid at rest.

The hydraulic particle size in an infinite liquid at rest is calculated depending on the flow regime [23].

Taking into account the formula (63), the system takes the following form

$$\frac{dh}{dx} = \frac{(1 + Ar\varphi)}{h^m}\frac{(gh^{2y+1}\cos\beta - gn^2u^2 + \varphi(1-\varphi)uh^{2y}w_0)(R - x\sin\beta) - u^2h^{2y+1}\sin\beta}{(gh\sin\beta - u^2(1 + Ar\varphi))(R - x\sin\beta)} \tag{64}$$

$$\frac{du}{dx} = \frac{[(gn^2u^3 - ugh^m\cos\beta)(1 + Ar\varphi) - \varphi(1-\varphi)w_0gh^m\sin\beta](R - x\sin\beta) + gh^{m+1}u\sin^2\beta}{(gh\sin\beta - u^2(1 + Ar\varphi))(R - x\sin\beta)h^m} \tag{65}$$

$$\frac{d\varphi}{dx} = -w_0\frac{\varphi(1-\varphi)^2}{hu} \tag{66}$$

$$\frac{d\Pi}{dx} = \varphi\frac{(R - x\sin\beta)}{\sin\beta}\frac{w_0}{q}. \tag{67}$$

To solve the system of equations (64)-(67), the initial values of the thickness of the pulp layer, velocity and concentration at x=0 (at the place of the pulp entering the bottom of the extraction chamber) are necessary.

The stream of the hydromonitor with the flow Q_w when hitting the wall of the breakout it reflects, loosens and erodes a certain amount of rock, which is characterized by the specific consumption of water on 1 м^3 the rock. Thus, the volume of washed rock per unit of time and the consumption of pulp entering the bottom of the extraction chamber will be equal

$$Q_p = \frac{Q_w}{A(1 - m_p)} \tag{68}$$

$$q_0 = Q_w\frac{1 - m_p + A}{A} \tag{69}$$

where Q_p - performance of the hydromonitor on solid; A - specific water consumption for erosion of this type of rock [23]; m_p - porosity of the rock in the residual state of extraction.

For a unit of time, the jet of the hydromonitor escribes an angle equal to $\omega=2\pi/T$, which on the surface of the breakout corresponds to an arc of a circle with a radius of R equal to $S_T=\omega R$. If at the point of contact of the jet with the wall of the breakout, the diameter of the jet is equal to d, then the total length of the perimeter of the contact of the jet with the rock is

$$L_T = S_T + d = \omega R + d \tag{70}$$

The value L_T is the width of the stream flowing down the wall of the breakout with the total flow rate q_0 in the initial section of the inclined surface of the bottom of the extraction chamber.

The flow of the pulp along the breakout wall before it reaches the bottom of the extraction chamber will be close to vertical. Therefore, the speed of the pulp at the moment it hits the bottom of the extraction chamber, if the effect of friction on the hole wall is neglected, can be determined by the formula

$$u_0 = k_U \sqrt{2g\Delta Z} \tag{71}$$

where ΔZ - is the distance between the point of contact of the jet axis with the breakout surface and the upper edge of the bottom surface of the extraction chamber; k_U - is an empirical coefficient that takes into account the influence of friction and other physical and mechanical factors.

Layer thickness h_0 can be obtained from the consumption equation

$$h_0 = \frac{Q_w}{(\omega R + d)} \frac{1 - m_p + A}{A k_U \sqrt{2g\Delta Z}} \tag{72}$$

Values u_0 and h_0, calculated by formulas (71) and (72), serve as initial values u and h for the system of equations (64)-(67).

From formulas (34)-(36) and (64)-(72) that the parameters of pulp flow along the bottom of the extraction chamber are largely determined by the operating mode and characteristics of the hydromonitor. Research has established that the flow of the pulp is most influenced by the feed of the hydromonitor, the radius of erosion, the area of the jet at the moment of contact with the rock.

Natural modeling of processes in the extraction chamber

The movement of the tuff hydromonitor destroyed by the jet to the suction device of the issuing device occurs in the flow along the bottom of the chamber by gravity or pressure flow of water. In addition, gravity delivery can be effectively used on the surface, from production wells to washout maps or pumping dredges [16-20].

Erosion of the chamber is carried out by sectors, which determines the presence of different specific consumption of the working agent along the length of transportation and leads to variability of flow rates. In the end, the factor of variability of specific consumption and velocities affects the transport capacity of the flow, which is minimal near the outcrop and increases in the direction of the output production. On the other hand, the amount of destroyed mineral is maximum near the extraction chamber and minimum near the outlet. Therefore, mineral losses near the breakout are quite large even in the first few meters of the erosion radius of the mining chamber, increasing (due to the superimposition of previous under-washes) as the breakout progresses. Over time, this leads to the impossibility of transportation of mined minerals without repeated erosion of the entire area of the sector. Increasing the transport capacity of the flow near the hole by increasing the flow rate of the working agent will lead not only to its significant overspending, but also to an increase in the productivity of hydraulic washing. In this way, the same problem arises - the impossibility of arranging such flow velocities on the periphery of the extraction chamber (near the outcrop) that would allow transporting the entire amount of reflected mineral [20]. This significant difference is the basis of research on hydraulic transport during borehole hydraulic production.

The reserve of potential energy of the open flow of the pulp is spent on the interaction of: the working agent with the bottom and walls of the chamber; liquid particles with each other (friction in the liquid); particles of the transported rock with each other and overcoming local resistances. It is not possible to quantify the energy consumption separately for each interaction, so the method of total evaluation of the flow work is adopted. The total work is expressed by the maximum transport capacity of the flow through the solid at a given slope of the bottom of the extraction chamber and the consumption of the working agent [25].

It is extremely difficult to study the parameters of the technology for extracting minerals from the chamber under natural conditions, so the experiments were conducted in the laboratory on a model stand (Fig. 7). It is practically impossible to carry out an absolutely appropriate simulation of well hydraulic extraction of tuffs, therefore the research results are only quantitative in nature.

The purpose of the studies on the selection of the working chamber scheme was to determine the most effective method of destruction and extraction of the rock, the selection of the extraction method, as well as the determination of the characteristics of the mining equipment. Three schemes of working out of the chamber were studied: oncoming, passing blowout and circulating flow.

According to the first scheme, mining operations were carried out in sectors around the mining well.

In the second scheme, development initially took place by driving mining wells through a channel with its subsequent expansion. At the same time, well hydromonitors work on each other, creating favorable conditions not only for destruction, but also for rock transportation in the chamber, since the energy of the hydromonitor stream is used most rationally when the directions of movement of the hydraulic mixture and the advancement of the hole coincide.

The third scheme is close to the first one and provided for the formation of the primary chamber not over the entire radius of effective action of the jet. The gradual and continuous rotation of the nozzle of the hydromonitor forms a circular circulation of the hydraulic mixture in the near-bump zone of the chamber. In this case, the energy of the stream is also used to transport the hydraulic mixture to the dispensing device.

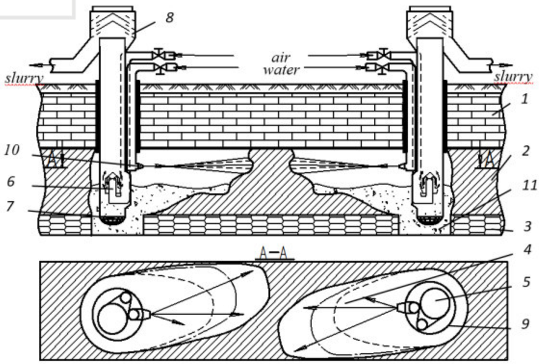

Fig. 7. Scheme of the stand for studying the technology of working out extraction chambers: *1* - roof rock; *2* - layer of zeolite-smectite tuff; *3* - underlying rock; *4* - extraction chamber; *5* - airlift; *6* - airlift nozzle; *7* - suction pipe; *8* - air separator plate type; *9* - column of casing pipes (well); *10* - hydromonitor; *11* - slurry

The experiments were carried out with the diameters of the nozzles of the hydromonitor d_0 equal to 4,2 and 6,0 mm, the change in water pressure H_0 from 0,2 to 0,7 MPa, and the thickness of the formation 0,08-0,19 m. Productivity of the airlift *5* and the density of the aqueous mixture *11* was measured with measuring containers. Model layer *2* is represented by zeolite-smectite tuffs from the basalt quarry of Ivanchi, taken from a depth of 15,2 m. The roof *1* and sole *3* of the layer were made of basalts and lava breccias, respectively. The walls of the laboratory installation were made of transparent glass to accurately determine the shape and dimensions of the chamber *4*. Pressure pads created an opportunity to load the formation.

Studies have shown that increasing the diameter of the nozzle and water pressure increase the washing rate and increase the efficiency of the extraction chamber, but the increase in efficiency is limited by the performance of the dispensing device. An increase in water pressure in the nozzle of the hydromonitor creates an increase in the density of the water mixture only up to a certain limit (ρ=1,3 g/cm^3).

The analysis of the research results showed that working out the formation in layers from top to bottom with a one-well production scheme creates favorable conditions for the flow of the hydraulic mixture to the discharge device. The scheme of working out the chambers with a passing hole is promising only for extracting the rock in the residual of extraction. A limitation to its use is a small angle of deviation from the axis of erosion.

Erosion of the layer and working out of the chambers by the circulation flow showed that regardless of the power of the spent rock layer, water pressure and diameter of the nozzle, the development stopped when the nozzle was rotated 25° from the initial position.

The process of working out the chamber with undercutting of the layer on the sole turned out to be less effective due to the collapse of the ore and disruption of the circulation flow. In the case of a working circulation scheme, it is better to increase the pressure on the nozzle to increase the flow rate. Flooding the camera dramatically reduces the efficiency of working out. Layer-by-layer mining with a circulating flow, all things being equal, reduces the working time of a chamber of the same size by about 25%.

The circulation scheme is very sensitive to changes in the operating modes of the hydromonitor and airlift, and therefore it is advisable to use it for rock with a uniform granulometric composition. Due to the limitation of the size of the product and the low stability of the circulation in the outcrop zone, the circulation scheme is less effective in comparison with the previous two. Its effectiveness was noted only at the beginning of the formation of the extraction chamber.

Thus, as a result of the conducted research, it was established that the most effective and promising application for borehole hydromining of zeolite-smectite tuffs is a single-well mining scheme with a counter strike, in which erosion occurs in sectors and round-shaped extraction chambers are formed. And taking into account that the roof of zeolite-smectite tuffs is thick layers of basalts, the most rational development system is a chamber system with an open cleaning space, in which tuff mining will be carried out in layers. The layers must be designed with a slope sufficient for gravity movement of the destroyed rock.

During the research, it was also established that for large particles (8-10 mm in size), the influence of the increase in flow occurs only until the liquid level rises to the height of the particle, that is, until it is completely immersed in the liquid. A further increase in the flow creates a much smaller effect in terms of the intensity of the effect on the particle, since the surface of the liquid does not come into contact with the plane of the particle, perpendicular to the vector of the speed of movement, and affects only the flow pattern. It can be assumed that with a further increase in the cost, the transportation range will increase, but the increase in the cost will lead to only a slight increase. This allows us to conclude that there is a limit to the influence of the increase in the cost of transporting particles of destroyed tuff.

In the experiment, the impact of the falling pulp flow on the transport capacity of the flow was also investigated. It was found that the initial energy of the falling pulp during washout intensifies the turbulence of the flow in the near-bump space and thereby reduces the probability of particle settling, creating the initial velocity of the falling particle. As a result of the impact, the particles of the reflected tuff become turbid, the density of the pulp increases and, as a result, the pushing force increases, which reduces the forces of adhesion of the particle to the bottom.

When the level of the pulp in the cavity of the chamber was high enough, the energy of the falling particle was extinguished by this layer and the settled particles could not move. In other words, there should be a turbulent movement on the periphery of the extraction chamber and a pulp level that is optimal for particle wear conditions.

To create the same conditions of transportation along the entire length of the section of movement of the reflected mineral in the extraction chamber, it is necessary to maintain a constant flow rate equal to the speed of reliable transportation. In this connection, it is necessary to create a rational, scientifically based profile of the bottom of the extraction chamber, which must meet the following requirements: - create an optimal (effective under the conditions of turbulence) flow depth in the hole. If the depth of the pulp in the extraction chamber is large enough (which is observed at small angles of inclination of the bottom), then the energy of the reflected rock particle will be extinguished when it falls and the deposited particles will not be able to be pulled into motion; - to create the maximum rolling force; - to have the optimal length of transportation of the reflected mineral.

Therefore, a rational profile should provide:

- constancy of the flow rate, equal to the speed of reliable transportation;

- the minimum consumption of mineral resources during structural design;

- the impossibility of sedimentation of the mineral to the bottom of the extraction chamber.

Conclusions

1. It has been established that the stability of the chamber workings required for supporting the roof rocks is ensured by layer-by-layer working of the mineral within the chamber with the simultaneous formation of inter-chamber the residual of extraction at full capacity, and their strengthening with a supporting prism made of the mineral for development depths of more than 50 m.

2. The surface of reliable hydraulic transportation is characterized by the radius of curvature L_{ki} , the value of which for discrete intervals $L_{npi}.L_{np2}$; $L_{np2}.L_{np1}$; L_{np1}...0 are constant. With an increase in the parameters of the depth of deposit development, the values of L_{np} and M are decreasing To create reliable hydraulic transportation on the surface of the underlying rocks, it is necessary to leave some volume of mineral, limited from below by the surface of the underlying rocks and the side surface of the cylinder with a diameter set by the erosion radius R_{ni}, or the limit span of the opening of the roof of the extraction chambers L_{npi}.

3. At depths of more than 50 m, the volumes of the reinforcing

prism may be significant, which will call into question the feasibility of using well hydraulic drilling systems. In this regard, it is proposed to extract the mineral within the contours of the chamber in several stages with the division of the capacity of the bed of rock *m* into a certain number of segments with a rational height. Thus, working out extraction chambers with the proposed technology allows to significantly increase production from one well and reduce losses of minerals.

4. Researched processes and established systems of equations for calculating dynamic models of pulp flow along the bottom of the extraction chamber. It can be seen from the formulas that the parameters of pulp flow along the bottom of the extraction chamber are largely determined by the operating mode and characteristics of the hydromonitor.

5. As a result of natural studies of the transportation process, it was established that the pulp falling to the bottom of the extraction chamber intensifies the turbulence of the flow in the near-excavation space by creating the initial speed of the pulp movement to the suction nozzle of the device, thereby reducing the sedimentation of tuff particles in the flow, the maximum height of which should not exceed more than twice the size of the largest fractions of the destroyed rock.

6. It was established that the dependence of the transport capacity of the flow on the flow rate of the hydromonitor and the slope of the bottom of the chamber for the destroyed zeolite-smectite tuff is linear and directly proportional to the specified parameters.

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