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DETERMINATION OF TECHNOLOGICAL PARAMETERS FOR HYDROMECHANICAL AMBER EXTRACTION IN THE POLISSIA REGION OF UKRAINE

Purpose. To develop and substantiate an effective methodology for determining the technological parameters for the use of hydraulic mining giants in the extraction of amber-bearing rocks, and to demonstrate the necessity of applying hydromechanical extraction methods for developing amber deposits in the Polissia region.

Methodology. A comprehensive approach was used to determine the technological parameters for hydromechanical amber extraction, involving a systematic analysis and generalization of the experience in amber extraction from amber-bearing rocks. The research focused on the classical scheme of hydromechanical extraction, with an emphasis on establishing an auxiliary pumping station to restore water levels lost during operations.

Findings. Based on the conducted calculations, the productivity parameters for the auxiliary pumping station were determined to be $Q = 72$ m^3/hour. The optimal pipeline diameter was selected as $D = 0.3$ m, and the optimal slurry velocity was determined to be $v_0 = 2.75$ m/s. The methodology for determining the technological parameters of hydromechanical amber extraction from amber-bearing rocks was substantiated, including the theoretical foundations for their calculation and the selection of extraction equipment.

Originality. For the first time, based on the analysis of the conducted research on the technological parameters for amber extraction from amber-bearing rocks in the Polissia region of Ukraine, a methodology has been theoretically substantiated and developed. This methodology determines the sequence of technological operations for the intensity of the process of destroying and washing out amber-bearing rocks by hydromechanical means.

Practical value. The research results propose the most efficient method for amber extraction. These results allow for the determination of optimal parameters for hydraulic mining giants in the hydromechanical extraction of amber-bearing rocks and overburden, thus improving extraction efficiency with minimal costs.

Keywords: *amber, hydraulic mining giant, overburden rocks, slurry, deposit, hydromechanical method, dredge pump*

Introduction. Ukraine is one of the few countries with substantial reserves of valuable minerals, the extraction of which meets both internal demands and supports exports, thereby fostering economic growth and strengthening the country's energy independence [1, 2]. One such valuable resource is amber, primarily mined in the Rivne region and renowned for its high quality, rendering it a crucial export commodity and contributing to the development of the jewelry industry. The Baltic coast stands out as the most renowned region for marine amber deposits. Coastal-marine amber deposits are widely distributed along the shores of contemporary seas and oceans, ensuring the availability of this precious gemstone in numerous countries [3].

Using Poland as an example, one can observe how small amber deposits are situated along the coast of the Gdańsk Bay. Additionally, amber is found along the North Sea coast in countries such as the Netherlands, Germany, and Denmark. The content of amber in the Stubbenefeld deposit on the island of Usedom amounts to 0.357 kg per cubic meter of rock, indicating a high concentration of this mineral. In Poland, amber extraction is predominantly concentrated in coastal areas along the Gdańsk Bay (Gulf of Gdańsk). This region boasts rich deposits of amber, with a long history of extraction. Particularly significant accumulations of Lower Miocene amber are located in Western Pomerania, specifically in the area of Słupsk. This location is renowned for its abundant amber deposits, which continue to be actively exploited to this day [4].

Various regions of the world possess their own unique amber deposits, each characterized by distinct geological and geographical features. The extraction of amber not only satisfies domestic demand but also contributes to the development of international trade.

In Ukraine, amber has been known since ancient times, and its utilization and extraction have deep roots. Historically significant amber extraction sites included areas around the city of Kyiv, such as Mizhhirya and Vyshhorod, as well as the Volyn region, particularly the vicinity of the settlement of Klesiv. Archaeological findings indicate that significant amber deposits were discovered in these areas as early as the *19th* century. One such discovery occurred near the city of Kyiv, where more than 50 pieces of amber of various sizes were unearthed, with a total weight exceeding 800 grams [5]. Natural processes significantly contributed to the spread of amber. The Dnipro River, along with other rivers, during floods and due to melting and rainfall, washed amber from ravines and streams, dispersing it across the terrain, which facilitated the accumulation of amber in various regions, making it accessible for extraction.

In ancient times, the extraction of amber was so efficient that it not only satisfied local demand but also enabled exports to other states. Ukrainian amber found its way to countries along the shores of the Mediterranean Sea, where it was highly prized. Such exports contributed to the development of trade and cultural ties between different nations. However, over time, surface amber deposits gradually became depleted, leading to decreasing profitability in extraction [6].

The largest deposits of amber in Ukraine are found in the Rivne, Volyn, and Zhytomyr regions. They are predominantly located in the northern parts of these regions at depths ranging from 2 to 30 meters. Currently, there is no precise assessment of the reserves due to limited exploration. In Ukraine, industrial-

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scale extraction of amber is carried out by state enterprises such as Klesivske, Volodymyrets-Eastern, and Vilne (Rivne region) [7]. However, due to insufficient funding, other potential deposits remain largely unexplored. At present, companies that have obtained licenses for the recultivation of areas previously exploited by illegal miners are allowed to continue extraction activities.

Geological surveys and assessment of amber reserves play a crucial role in decision-making regarding its extraction and utilization [8]. The importance of exploration and assessment of amber extraction lies in their impact on the economy, social development, and ecology. Exploration enables the discovery of new resource deposits and the assessment of their potential for extraction. This stimulates investments and the development of industries related to the extraction and processing of natural resources, thereby creating job opportunities and increasing income. Additionally, accurate reserve assessment allows for the development of strategies for economic growth and ensures the stability of resource supply [9].

Equally important is the ecological aspect, as exploration and extraction of amber can have a negative impact on the natural environment [10]. Therefore, it is essential to conduct exploration and assessment while considering the principles of sustainable development and preservation of natural resources for future generations, considering environmentally sensitive and protected areas in Western Polissia.

According to the provisions of the “State Cadastre of Mineral Deposits and Manifestation”, the state accounting aims for the continuous determination of the country’s mineral resource base, forecasting its development prospects, ensuring rational use, and protection of subsoil. All deposits of mineral resources identified on the territory of Ukraine are subject to accounting, regardless of the size of their reserves, the level of exploration, the state of development, industry affiliation, or conditions of occurrence. State accounting includes data on both the total reserves of mineral resources and associated mineral components, as well as extractive reserves, considering possible losses and fragmentation during extraction and processing of mineral raw materials. Such an approach enables accurate monitoring and efficient management of the country’s resources, facilitating their rational utilization and preservation for future generations.

Literature review. The extraction of amber from sandy deposits is usually performed using two methods: mechanical and hydraulic. Each of them has its own advantages and disadvantages, as well as a different impact on the environment.

The mechanical method involves soil development in open pits or underground using mechanical means [7]. This process includes uncovering the top layer of soil to expose the amber deposit; extracting soil containing amber using excavators or other machinery; transporting the extracted soil to processing areas for separating the amber; rinsing to extract amber pieces from the soil and cleaning the remaining soil residues while restoring land resources. Disadvantages of the mechanical method include high operational and economic costs. Soil mixing and removal to the surface can lead to erosion and land degradation [11]. Additionally, there is a negative impact on the environment, including water body pollution and destruction of natural ecosystems [12].

The hydraulic method involves utilizing a high-pressure water jet to erode the soil and bring the amber to the surface [13]. This process comprises delivering high-pressure water to the extraction site, breaking down the soil to release the amber (as amber pieces, lighter than the soil, rise to the water surface), collecting the amber pieces from the water surface, and cleaning the remaining soil residues while restoring land resources. Disadvantages of the hydraulic method include depletion of water resources, the requirement for powerful pumps and equipment, and the potential for damaging the amber pieces during extraction.

There are other methods of hydro-mechanical mineral extraction, which involve the use of mixtures of different viscosities; however, such methods are rarely used in mainstream hydro-extraction processes. One effective method involves injecting a viscous, possibly non-freezing, liquid into a pre-prepared borehole [14]. This liquid mixes with the soil, forming a slurry. Due to the difference in density of the components, heavy fractions settle at the bottom of the borehole, while lighter ones are pumped to the surface along with the soil. This method is particularly useful when working with frozen ground, where traditional methods may be less effective [15]. The viscous liquid not only helps to soften the soil but also facilitates the easy transportation of valuable minerals to the surface. Moreover, such an approach allows for the effective sorting of valuable minerals by their density, thereby enhancing the quality of the extracted material. Thus, although the use of mixtures of different viscosities is not the primary method of hydro-extraction, it has its specific advantages that make it indispensable under certain conditions. This approach continues to evolve, and in the future, broader application in the mining industry can be expected [16, 17].

The aforementioned method is energy-intensive, which increases extraction costs and renders the process less economically viable. Additionally, the use of these methods results in the loss of soil structure and the formation of voids, which can lead to soil subsidence and other geotechnical issues when placing mining equipment [18]. Furthermore, they have a significant techno-ecological impact on the environment. The application of such extraction methods contributes to landscape degradation, pollution of water resources, and a decrease in biodiversity. Overall, these issues call for the development and implementation of more resilient and environmentally friendly mineral extraction technologies [19].

The selection of a method depends on the specific conditions of the deposit, economic considerations, and environmental regulations. It’s crucial to employ methods that minimize adverse environmental effects and guarantee the sustainable extraction of amber [20, 21].

At the National University of Water and Environmental Engineering (NUWEE), an enhanced hydro-mechanical method for extracting amber from amber-bearing sand deposits has been developed [22]. This innovative technology aims to enhance the efficiency of amber extraction while minimizing its environmental footprint. The primary advantage of this new method lies in its ability to extract amber more effectively from sand deposits, achieved through advanced technology for mixing soil with liquid, thereby reducing losses of valuable material during extraction. Furthermore, the improved method prioritizes soil structure preservation, thereby mitigating the formation of voids and ensuring the stability of land areas. With its numerous advantages, the enhanced hydro-mechanical method holds the potential to become the predominant technique for amber extraction in the future. It exemplifies how scientific and technological advancements can contribute to sustainable development and the conservation of natural resources, representing a significant stride in mineral extraction by seamlessly blending efficiency with environmental safety.

The essence of the described method is as follows: the mass is activated through mechanical agitation and saturated with water to create a continuous suspension layer, reaching a density that generates an uplifting force, lifting the amber to the surface of the deposit. Through mechanical action (in the presence of water), the mass loses cohesion between particles, releasing the amber and achieving a suspension state with a density greater than the specific gravity of the amber. This allows the amber to float to the surface of the deposit according to Archimedes’ principle [23]. Meanwhile, the excavation of overburden by excavator represents the most energy-intensive and resource-consuming process in open-pit mining, significantly impacting the overall cost of extraction [24].

Unsolved aspects of the research. Reducing the high cost of amber extraction by minimizing expenses associated with overburden removal through hydraulic mining remains a significant and unresolved aspect of amber mining. This method enables a reduction in the number of workers and automotive transport units, thereby decreasing energy resource expenditures. Additionally, equipment operation using the hydraulic mining method is simpler and less expensive compared to the excavator method.

The purpose of the study. The study aims not only to uncover new insights but also to refine established knowledge in mining science concerning the methodology for determining the parameters for the application of hydraulic mining equipment in extracting amber-bearing deposits. Given the feasibility of the hydraulic method for amber extraction, it is necessary to determine the specific parameters for using hydraulic mining equipment. This involves determining the productivity of the dredge, the productivity of auxiliary and main pumping stations, the pipeline diameter, the velocity of the hydraulic mixture, the volume of the sump, the operational water velocity in the pipeline, and the total head loss of the water. Therefore, it is essential to define these parameters for the effective development of amber-bearing deposits using hydraulic mining equipment.

Methodology. In the study of determining the technological parameters for hydraulic amber extraction, a systematic approach was employed, encompassing the analysis and synthesis of existing experiences from amber-bearing deposits. The research methodology comprised several stages. Initially, a detailed review of current amber extraction methods was conducted to identify their advantages and disadvantages. Subsequently, an investigation of hydraulic mining schemes was carried out, focusing on the use of auxiliary pumping stations to restore water levels reduced by production losses. Based on the data obtained, recommendations were developed to optimize the extraction process, particularly concerning the efficient use of water resources and the reduction of production losses.

According to geological surveys of the Klesiv amber-bearing deposit, the amber-containing formations are composed of quartz sands mixed with glauconite and dark-colored minerals. These sands vary in grain size, being predominantly medium-grained, dark gray, slightly clayey, and water-saturated with quartz gravel content. The terrigenous material of the sands is moderately rounded. Small fragments of brown-colored wood and amber grains are also present. Occasionally, lens-shaped layers of gray-blue and dark-blue clays with quartz inclusions and small amber grains are found [25, 26].

The thickness of the upper sand horizon in the working area varies from 2.0 to 4.0 meters, with an average thickness of 3.0 meters. The clay layer has a maximum thickness ranging from 3.6 to 5.0 meters on the southern boundary of the area, gradually thinning out towards the west and north, to a range of 0.0 to 0.5 meters. These clay formations occupy the lower parts of the terrain, effectively leveling it to a nearly flat state. The absolute elevations of the base of the fine-grained sand layer show minor variations, ranging from 153 to 165 meters.

The area of the site is located in a region affected by the Chernobyl disaster, characterized by marshy conditions drained by drainage canals. The hydrographic network of the area belongs to the basin of the Sluch River, a right tributary of the Prypiat River, known for its high-water levels and extensive flooding during periods of high water. In the spring, about half of the annual surface runoff occurs, and during the spring-summer period, it accounts for approximately 80 % of the annual total.

The duration of the period with positive daily temperatures in the area is approximately 260 days. During this time, about 75 % of the annual precipitation occurs, which is the main source of groundwater recharge. The daily maximum rainfall is 89 mm. Snow cover forms in the second half of December and is characterized by significant variability, ranging from 0.1 to 0.5 meters. In winter, precipitation often falls as wet snow and rain. Snowmelt occurs from late February to early March. The moisture content in the snow cover averages 25–40 mm. The annual surface runoff reaches 75 % of the annual precipitation volume.

The aquifer complex is located in the lower layers of the geological cross-section and contains groundwater. It is unconfined across its entire area, with the depth of its water table varying significantly – from 0.5 meters in low-lying areas to over 2.5 meters on elevated terrains formed by terminal moraine hills. The primary recharge of the aquifer complex occurs through the infiltration of atmospheric precipitation. Water seeps through the aeration zone, especially when the aquifer is closest to the surface. Additionally, recharge occurs via downward flow from other aquifer layers located above it. The discharge processes of the aquifer complex are concentrated within the watershed areas, where water flows downward to lower aquifer layers. These processes play a crucial role in forming the region's hydrological regime, redistributing water resources among various groundwater levels. Thus, the aquifer complex operates through the interaction of recharge and discharge processes, maintaining the groundwater balance in the region. This balance is critical for sustaining ecological equilibrium and meeting the water needs of the local population and economy.

The water saturation of the territories and the host rocks was tested using both single and clustered pump tests, typically conducted with wells that fully penetrate the horizon. In sections predominantly composed of silt, the filtration coefficients range from 0.10–0.30 m/day with a water level drawdown of 2.0–3.0 meters, while in variously grained sands, the coefficients range from 0.2–2.0 m/day with a drawdown of 2.5–5.0 meters.

Since the fertile soil layer has been damaged due to unauthorized amber extraction, it is categorized as overburden. According to geological surveys, the primary explored amber deposits are located in the northern regions of Polissia, in ecologically contaminated and protected areas with high groundwater levels. For their industrial development and extraction, modern methods and technologies need to be applied.

Research on the technological parameters of hydraulic amber extraction in the Rivne-Volyn region was conducted based on an analysis of previous research results. The theoretical foundations of well-based hydraulic extraction are grounded in established laws of hydromechanics, the physics of rock formations, mechanics, and economics, and their application in hydraulic mechanization. Analyzing the physical, geological, technological, and economic factors is fundamental to the method of hydraulic amber extraction from sandy and sandy-clay deposits.

The term "hydraulic extraction" is currently acceptable, as the specific weight of the water used for destruction, erosion, disintegration, gravity hydraulic transport, and other operations predominates in the overall energy balance compared to compressed air, surfactants, solid components, and so on.

In the hydraulic method, which is used in dry excavations, the soil is eroded by a water jet that exits the nozzle of the hydraulic mining giant under high pressure and at a high velocity (up to 120–160 m/s). The water is supplied to the hydraulic mining giant through a pipeline system from a pump station, usually located near a water reservoir or on a floating pontoon. When the jet strikes the soil, the elementary water jets penetrate between the soil particles, disrupting the interaction of friction and cohesion forces, leading to the detachment of particles from the overall mass. The greater the degree of water penetration into the soil, the more intense its disintegration. As a result, the water mixed with the eroded soil forms a slurry which, with favorable terrain, is removed by gravity to the deposition site via steep channels or flows into a sump, from where it is pumped by a special ground pump known as a dredge pump.

The effective soil development through hydraulic mining relies on the design of the hydraulic mining giant, water pressure, and the distance of the hydraulic mining giant from the bench face. The hydraulic mining method for soil development in the construction of large hydraulic structures is primarily utilized for auxiliary tasks [27].

The labor intensity of forecasting and determining the direction of development for sampling and extraction systems, as well as the equipment used to ensure their operability and the overall technology for sampling and extracting valuable mineral components through the discussed methods, is challenging not only due to the currently limited experience of their application but also because of the practically non-existent application for amber. Additionally, there is a significant discrepancy in the mining and geological characteristics of deposits and host rocks.

To create effective development systems, it is important to determine specific technical solutions that reduce the specific costs of testing the object, pilot operation, and mineral extraction. This can be achieved by considering the favourability of mining and geological conditions, the utilization of extraction reserves, the degree of perfection of technological processes and technical means, the reliability of equipment, wells, and workings that ensure the process, the optimality of system elements and parameters, the degree of system automation, and ensuring high quality and simplicity of equipment nodes and the variety of interchangeable elements of the working body design [28, 29].

The degree of favorability of mining and geological conditions should be understood as a set of factors that, during the sampling and development of deposits by traditional methods, usually hindered the application of systems or led to an increase in the cost of any of them. However, in the studied methods, these factors either play a positive role or do not significantly change the economic indicators compared to traditional methods [30].

For the extraction of deposit areas in the Rivne-Volyn region, a suitable method is hydraulic backfilling of the worked-out space of excavation chambers. This method is based on using the energy of water flow for transporting and laying the backfill material. The placement of material in the worked-out space occurs by gravity under the action of the backfill material's weight. The backfill material should have high transportability with minimal water consumption, readily release water, contain a certain amount of clay particles (around 15 %), and be of low cost.

The lower limit of the particle size of the laying material is determined by the need to remove fine fractions with water from the excavated space of the chambers, while the upper limit is defined by the requirement of normal pulp transportation through pipelines and the creation of a cohesive laying mass. The fluidity of the pulp depends on factors such as the consistency of solid and liquid phases (S:L ratio), density of the laying material, particle size and shape, and pipeline parameters. The S:L ratio characterizes the consistency of the pulp, determining its density and fluidity. A high S:L value indicates a higher quantity of solid phase relative to the liquid, making the pulp denser and less fluid. A low S:L value means that the pulp is more diluted and easier to move.

Once the laying material settles, a portion of the excavated chamber space is filled with pulp. This process is repeated in cycles. A closed water supply system of the hydro-mechanical extraction complex is used as the laying equipment for pulp hydro-transportation. In this system, the suction nozzle of the ground pump operates according to a tracking system at the bottom of the settling pond to maintain the most advantageous consistency of the pulp, which is then delivered into the excavated chamber space.

In the research area of the hydro-mechanical extraction method of amber in the Rivne region, pulp from the settling pond was used as the laying material, which was periodically supplied to the excavated space of the worked-out chambers. Studies have established the average ratio of solid to liquid in the pulp, which is equal to 1 : 1–1 : 2.

Results. In the hydro-mechanical method of mining, both the overburden and amber-bearing rocks should be extracted in stages, with specific tasks carried out in respective blocks. The first block involves hydraulic mining of the soil, the second block is mechanical (excavator) extraction of the valuable mineral, and the third block is the hydraulic backfilling of the overburden and waste rock.

During hydraulic mining, the sandy soil is eroded by a water jet that creates the necessary pressure for the erosion of the sandy mass. The slurry from the cutting face flows to the slurry receiver – the sump. The sump is an excavation resembling a shallow well on the platform of the slope, from which the slurry is pumped out by a slurry pump.

At the overburden dumping site (hydraulic backfill), the slurry flows out of the pipeline. The settled water is collected using a pump and then pressurized before being fed back to the hydraulic mining giant. During this process, a certain amount of water is lost due to evaporation, filtration, etc. To compensate for these losses, an auxiliary pumping station (APS) is installed near the water body, which delivers the lost water to the receiver of the main pumping station (MPS). In this case, recycled water is utilized (Fig. 1).

The primary working equipment in hydraulic mining is hydraulic mining-dredge pump equipment. It comprises an auxiliary pumping station that supplies water to the receiver of the main pumping station. The main pumping station delivers water at the required pressure to the hydraulic mining giant, a suction pump for pumping the slurry to the hydraulic backfill, and the necessary number of pipelines for water and slurry transportation.

Hydraulic mining giants are classified based on the pressure level into three main categories: low pressure (~1.0 MPa), medium pressure (<4.0 MPa), and high pressure (>4.0 MPa). The fluid movement in the jets is characterized by the displacement of water particles in conditions where solid channel boundaries are absent, creating unique conditions for studying flow dynamics. When the jets move, they can mix with other fluids of varying densities. This process is further complicated when dealing with multiphase systems. For example, the jet substance and the medium substance may exist in different physical states, such as gaseous or liquid. Additionally, solid particles may enter the jet, forming a boundary layer. These complex phenomena arising during the movement of multiphase jets or the mixing of fluids with different densities are so intricate that current analytical methods cannot fully describe them.

The formation of the jet in the hydraulic mining giant has its own specifics. As the water flow moves towards the nozzle, it encounters various obstacles along its path, leading to turbulence and cavitation. These phenomena adversely affect the quality and parameters of the hydraulic mining giant jet, reducing its efficiency. The final formation of the jet occurs in the nozzle. The main purpose of the nozzle is to convert the static

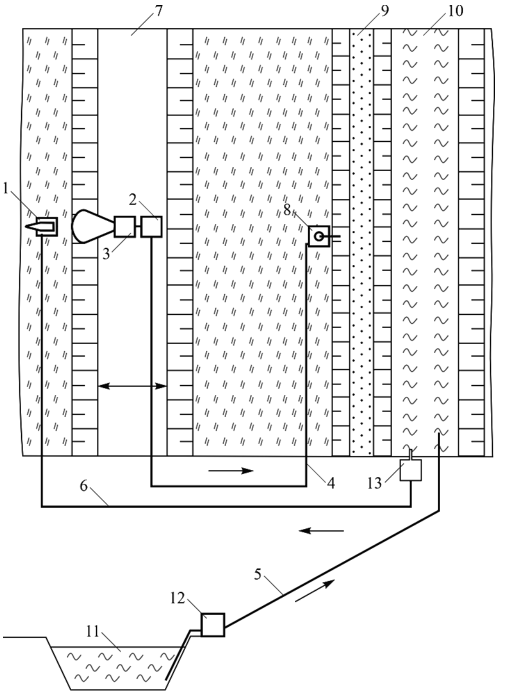

Fig. 1. Schematic diagram of water movement:

1 – hydraulic mining giant; 2 – dredge; 3 – sump; 4 – slurry pipeline; 5 – water supply pipeline; 6 – pressurized water pipeline; 7 – pit; 8 – sluicing device; 9 – hydraulic dump; 10 – water purification pond: 11 – water basin; 12 – auxiliary pumping station; 13 – main pumping station (MPS) pressure of water into the kinetic energy of the jet by reducing the nozzle's cross-section, which increases the speed of its movement while maintaining a constant water flow rate. This process simultaneously leads to an increase in pressure losses, which are proportional to the square of the flow velocity. In the final cross-section of the nozzle, the transition from static pressure to velocity pressure occurs without pressure losses. This process is critical for the efficiency of the hydraulic mining giant as it ensures the maximum possible speed of the water jet required for effective soil erosion. Optimizing the design of the nozzle and reducing the influence of turbulence and cavitation are important tasks for improving hydraulic mining giants.

For the hydraulic mining development of rock formations, let's explore the methodology for determining the parameters of using hydraulic mining equipment using a specific example. Water losses for a cutting height of 3–5 meters and rock of categories III-IV are recommended to be 7–9 m^3/m^3. The pressure ahead of the hydraulic mining giant nozzle is set between 1.2–2.0 MPa.

The volume of rock excavation per hour for an 8-hour workday is calculated as follows

$$Q_r = \frac{V}{T},$$

where V – the volume of the block in cubic meters, m^3; T – the duration of the shift in hours, hours.

When using 7 m^3 of water per 1 m^3 of rock, approximately 679 m^3/hour of water will be needed.

For water supply from the main pumping station to the hydraulic mining giant, a centrifugal pump 1OMNK × 2 with a capacity of 720 m^3/hour was selected. The volume of slurry that needs to be pumped per hour is 822 m^3/hour. A standard suction dredge 8NZSU with the nearest hourly productivity of 850 m^3/hour was chosen based on the productivity of the suction dredge.

Since the technological scheme involves the use of recirculating water, it is necessary to determine the productivity of the auxiliary pumping station, which would replenish the recirculating water losses. The productivity of the auxiliary pumping station is determined by the formula, m^3/hour

$$Q = 0.01 \cdot QH \cdot p,$$

where p – the water loss during circulation, % (approximately 10 % is typically assumed for sandy soils); QH – the productivity of the main pumping station, m^3/hour.

When operating with recirculating water, an additional 576 m^3 per shift is required daily. To supply water to the auxiliary pumping station from the main pumping station, a centrifugal pump with a capacity of approximately 72 m^3/hour is needed. The initial data for the final calculations and selection of technological hydraulic equipment are provided in Table 1.

We determine the volume ratio (in compact form) to the liquid S : L = 1 : 7. The volume ratio of solid in bulk to liquid is defined as 1 : 5. The mass concentration of water is 1 : 3. The volume concentration of solid in the slurry (S) is 0.125. We calculate the density of the slurry using the formula, kg/m^3

$$p_c = S \cdot (p_S + p_0) + p_0.$$

Therefore, the density of the slurry will be 1,187 kg/m^3. According to calculations, the relative density of the solid in water is $\alpha = 1.5$. We will select the most optimal diameter of the pipeline

$$D = 2 \cdot \sqrt{\frac{Q}{\pi \cdot v_k}};$$

$$v_k = 8 \cdot \sqrt[3]{D} \cdot \sqrt{S \cdot \psi_t},$$

where ψ_t – the coefficient of transportability in heterogeneous rock

$$\psi_t = \frac{\psi_{tj} \cdot P_j}{100},$$

Table 1

Initial data for the final calculation of technological equipment

No.	Parameters	Units	Values
1	Annual volume of overburden rock extraction	m^3	173,332.2
2	Number of working days in the season	days	226
3	Number of working shifts per day	pieces	1
4	Volume of overburden rock extraction per hour	m^3/hour	97.12
5	Density of overburden rock in loose form	kg/m^3	1,950
6	Bulk density of rock in solid form	kg/m^3	2,500
7	Maximum possible distance for waste transport	m	350
8	Geodetic height of slurry feed	m	7
9	Composition of sand fraction larger than 5 mm	kg	2–0.5
10	Composition of sand fraction larger than 2 mm	kg	5
11	Composition of sand fraction smaller than 2 mm	kg	95

where ψ_{tj} – the average magnitude for the j^{th} fraction; P_j – the percentage content of the j^{th} fraction.

For the sand of the average fraction, the percentage content is provided in Table 2.

After performing the calculations, we obtain: $\psi_t = 0.44$; $v_k = 3.22$; $D = 0.297$. The nearest standard diameter of the pipeline is $D = 0.3$ m (internal diameter).

We determine the operational velocity of the hydraulic mixture using the formula

$$v = \frac{Q \cdot 4}{3600 \cdot \pi \cdot D^2}. \tag{1}$$

The working velocity of the hydraulic mixture will be 3.24 m/s.

We determine the optimal velocity of the hydraulic mixture

$$v_0 = 5.5 \cdot \sqrt[6]{S \cdot \psi_t \cdot D}.$$

The optimal velocity of movement for the hydraulic mixture will be 2.75 m/s.

The specific flow rate in the pipeline during the movement of water is determined by the formula

$$l_l = \lambda_r \cdot \frac{V^2}{2 \cdot g \cdot D}, \tag{2}$$

where l_l – the specific head loss in the pipeline during the flow of water with velocity V; λ_r – the coefficient of resistance of the pipeline.

To determine the resistance coefficient (λr) during the flow of water in the pipes, we use the formula

Table 2

The dependence of the transportability coefficient on the percentage content of the sand fraction

No.	Fraction content (P_j), mm	Transportability coefficient (ψ_t)
1	2.0–1.0	5.0
2	1.0–0.5	14.9
3	0.5–0.25	58.6
4	0.25–0.1	17.9

$$\lambda_r = D^{\frac{0.24}{0.226}} \cdot \left(1.9\cdot 10^{-6} + \frac{V}{v}\right)^{0.226}, \qquad (3)$$

where V – the dynamic viscosity coefficient.

We choose $V = 167 \cdot 10^{-8}$, m^2/s and calculate $\lambda_r = 0.027$ and $l_l = 0.008$.

The calculation of the specific head loss due to friction during hydraulic transport of sandy soils in pressure pipelines is performed using the formula

$$l_{h.t} = l_l \cdot \left(1 + 2\cdot\left(\frac{v_0}{v}\right)^3\right).$$

In general, when working with a dredge, the total head losses along the pipeline consist of losses due to friction along the main pipeline length, losses in the floating pipeline, losses in the pipelines and fittings inside the dredger body, losses in local supports, as well as energy expenditures for the elevation of the hydro-mixture.

In project specifications, the head losses of all local supports along the pipeline from the dredger to the discharge point of the hydro-mixture can be assumed to be 10 % of the head losses due to friction along the pipeline length. The total head losses of the hydro-mixture are expressed as

$$H = k \cdot (l_{h.t} \cdot l_1 + 0.1 \cdot (l_{h.t} \cdot l_1)) + h_g, \qquad (4)$$

where k – safety factor, $k = 1.1$; l_l – length of the pipeline; h_g – head loss due to the geodetic rise of water, calculated by the formula, m

$$h_g = \pm h \cdot \frac{p_c}{p_0}, \qquad (5)$$

where h – the difference in elevation between the water level (near the dredge) and the axis of the pipeline at the point of discharge of the hydraulic mixture.

The "+" sign in formula (5) is taken in the case of raising the pipeline, and "–" in the case of lowering, where $h_g = 8.3$ m. Then, the head loss due to friction over the length of the pipeline will be $H = 16.07$ m. The standard soil dredge 8NZU 850/28 fully meets the required productivity and head loss criteria.

The volume of the sump is determined by calculating the necessity for a 2-minute productivity of the dredge, according to the formula, m^3

$$V = \frac{Q \cdot t}{60},$$

where Q – productivity of the dredge in hour; t – the required working time ($t = 2$ min); 60 – the number of minutes in one hour.

Therefore, the volume of the sump will be 28.34 m^3.

The suction height of dredge 8NZU 850/28 is 7 m. We determine the area occupied by the sump, which is 9.44 m^2. Then, using a trial-and-error method, we determine the length and width of the sump. The results are summarized in Table 3. The initial data for calculating the parameters of the technological water supply for hydraulic mining giant HDK-250 for breaking up overburden rocks are provided in Table 4.

Since the calculated water demand is 679.84 m^3/h, we select the closest pump in terms of productivity, the 1ONMK×2 pump. To standardize the equipment, we use pipes with an internal diameter of $D = 300$ mm for transporting the slurry. The piping system for supplying water to the hydraulic mining giant and for rock excavation consists of pipes connected together using quick-connect fittings. The working velocity of water flow in the pipeline is determined by formula (1) and it amounts to 2.83 m/s.

Next, we determine the specific head losses in the pipeline using formula (2). Specific head losses in the pipeline for the flow of clean water are determined using formula (3) to find the coefficient of resistance (λ_r) for water flow in pipes. We select a kinematic viscosity coefficient $V = 167 \cdot 10^{-8}$. The calculation shows that $\lambda_r = 0.02$ and $l_l = 0.005$.

The calculation of the total head losses of water is found using formula (4). The obtained value is $h_g = 8.33$ m.

For the excavation of rock, we select the centrifugal pump 1ONMK×2 720/204, which fully meets the technological requirements with its technical characteristics. Thus, the 1ONMK×2 720/204 pump, operating on a pipeline with a diameter of $D = 300$ mm, will provide a head of 204 – 8.33 = = 195.67 m with a length of 600 m.

The auxiliary pump station is intended to replenish water lost from the circulating system due to evaporation, filtration, etc. The productivity of the auxiliary pump station should neither be significantly less than nor exceed 72 m^3/hour. We determine the head losses along the section from the auxiliary pump station to the main pump station. The initial data for determining the head losses are provided in Table 5.

To standardize the technological equipment, we select a pipeline diameter of $D = 300$ mm. The pipeline system for supplying water to the main pumping station consists of pipes connected using flange joints. The working water velocity in the pipeline is determined using formula (1), and the resulting working velocity of the water in the pipeline is 0.1 m/s. The specific head loss in the pipeline for the flow of clean water is determined using formula (2). To determine the resistance coefficient (λ_r) for water flow in pipes, we use formula (3). The calculation shows that $\lambda_r = 0.3$ and $l_l = 0.0005$.

The total head loss of water is calculated using formula (4), resulting in frictional head losses along the pipeline length of $H = 131.65$ m.

Table 3

Geometric parameters of the sump

No.	Parameters	Units	Values
1	Volume	m^3	28.34
2	Length	m	3.14
3	Width	m	3
4	Depth	m	3

Table 4

Input data for water supply calculation

No.	Parameters	Units	Values
1	Maximum distance for water supply from the auxiliary pumping station (APS) to the main pumping station (MPS)	m	300
2	Maximum distance for water supply from the main pumping station (MPS) to the hydraulic mining giant	m	600
3	Minimum required amount of water for rock excavation	m^3/hour	679.84
4	Difference in geodetic elevations between APS and MPS	m	30
5	Difference in geodetic elevations between the hydraulic pump and MPS	m	0–5

Table 5

The initial values for determining the head losses

No.	Parameter	Unit	Value
1	The maximum distance for supplying water from the auxiliary pumping station (APS) to the main pumping station (MPS)	m	300
2	The difference in elevation between the APS and MPS	m	30
3	The minimum required quantity of water	m^3/hour	72

For replenishing water from the reservoir, we choose a centrifugal pump CN 90/30. For the excavation and hydraulic mining of overburden, we select a remotely controlled hydraulic mining giant HDK-250. The input values for determining head losses are presented in Table 6.

To relocate the hydraulic mining giant to a new work site with minimal loss of time and labor, the following steps should be taken:

- prepare the new site for the hydraulic mining giant using its jet;
- disconnect the hydraulic mining giant from the pipeline;
- move the hydraulic mining giant to the new location;
- extend the pipeline;
- connect the hydraulic mining giant to the pipeline at the new location.

Before disconnecting the hydraulic mining giant from the pipeline, it is crucial to shut off the water supply. This is done by closing the nearest valve. After this, the hydraulic mining giant can be disconnected from the pipeline. Once disconnected, the pipes are laid along the axis of the extended pipeline and connected.

Before starting to relocate the hydraulic mining giant, the pipe joints should be cleaned of dirt and a new section prepared. The hydraulic mining giant is then moved to the new work site using available mechanization.

When receiving and placing soil into structures, profile embankments, and dumps, the areas where the soil is to be placed must be marked with signs warning of danger and prohibiting unauthorized access to the structure or the hydraulic fill being created. During the placement of soil on the fill maps, it is necessary to monitor the condition of the dams as well as the reliability of the water drainage systems (pipes, channels, etc.). If an increase in filtration is detected on the dam slopes, clogging of collection wells, overflow of water over the dam, or other issues, an emergency signal should be issued, and measures taken to address the problem.

The fill map is filled with soil in such a way that the dam exceeds the level of the deposited soil by at least 0.4–0.5 meters. Cleaning or repairing the collection well is carried out when the slurry supply to the map is suspended and only after it has been completely drained. Access to the collection well for inspection and extension is allowed via bridges that are equipped with railings.

During breaks in operation, collection wells are covered with shields or fenced off, and during nighttime, they are illuminated. The same measures are applied to wells located in completed areas. Repair work in collection wells deeper than 4 meters is conducted under the supervision of engineering and technical personnel. Any worker descending into the well, regardless of its depth, must be tethered around the waist with a rope, the end of which is secured to the top of the well casing.

Access to a freshly filled map with fine-grained sands is prohibited. Approaching the settling pond is not allowed. Bulldozers or other machinery are only allowed onto the fill map after the soil density has been checked. However, it is forbidden to adjust the flow direction of the slurry as it exits the pipe using shovels, planks, or other objects.

Table 6

Initial Data for Determining Pressure Losses

No.	Parameters	Units	Values
1	Inlet diameter, *D*	mm	250
2	Available pressure	atm	15
3	Nozzle diameters (applicable)	mm	51; 63.5; 76.5; 89; 102
4	Barrel length	mm	2,525
5	Angle of rotation: - upward - downward - to the right - to the left	degrees	 32 28 55 55
6	Overall dimensions: - length - width - height	mm	 4,175 1,500 1,290
7	Weight	kg	1,013

Conclusions. The conducted research aimed at determining the fundamental technological parameters of hydraulic mining equipment has led to the development of a methodology for determining the technological parameters of hydromechanical amber extraction from amber-bearing rocks. The theoretical foundations for their calculation have been established, and hydraulic extraction equipment has been selected.

The research on the main technological parameters of hydraulic mining equipment has facilitated the development and justification of an effective methodology for determining the technological parameters of hydraulic mining equipment application for extracting amber-bearing rocks. It has also substantiated the necessity of employing hydromechanical extraction for developing amber deposits in the hydrogeological conditions of the Polissia region.

Based on the analysis of the conducted research on technological parameters for amber extraction from amber-bearing rocks in the Polissia region of Ukraine, a methodology has been theoretically substantiated and developed for determining the sequence of technological operations and the intensity of the process of breaking down and washing amber-bearing rocks using the hydromechanical method.

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Визначення технологічних параметрів гідромеханічного видобутку бурштину в Поліському регіоні України

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Мета. Розробити та обґрунтувати ефективну методику визначення технологічних параметрів застосування гідромоніторного обладнання для розробки бурштиновмісних порід і необхідність застосування гідромеханічного видобутку для розробки родовищ бурштину в умовах Поліського регіону.

Методика. У роботі із визначення технологічних параметрів гідромеханічного видобутку бурштину було застосовано комплексний підхід із систематизованого аналізу узагальнення досвіду видобутку бурштину з бурштиновмісних порід. Дослідження виконувалося для класичної схеми гідромеханічного способу розробки із акцентом на встановлення допоміжної наосної станції для відновлення рівня води, що зумовлене виробничими втратами.

Результати. На основі проведених розрахунків отримані параметри продуктивності допоміжної насосної станції Q = 72 м^3/год. Підібрано оптимальний діаметр трубопроводу D = 0.3 м і визначена оптимальна швидкість гідросуміші v_0 = 2.75 м/с. Обґрунтована методика визначення технологічних параметрів гідромеханічного видобутку бурштину з бурштиновмісних порід, теоретичні основи їх розрахунку та підібране гідровидобувне обладнання.

Наукова новизна. На основі аналізу проведених досліджень технологічних параметрів для видобутку бурштину з бурштиновмісних порід Поліського регіону України вперше теоретично обґрунтована й розроблена методика визначення послідовності технологічних операцій інтенсивного процесу руйнування й розмиву бурштиновмісних порід гідромеханічним способом.

Практична значимість. За результатами досліджень запропонований найбільш ефективний спосіб видобутку бурштину. Отримані результати дають змогу визначити оптимальні параметри гідромоніторного обладнання для гідромеханічного способу розробки бурштиновмісних порід і порід розкриву, що дасть змогу підвищити ефективність видобутку з мінімальними затратами.

Ключові слова: *бурштин, гідромонітор, породи розкриву, пульпа, родовище, гідромеханічний спосіб, землесос*

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