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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.

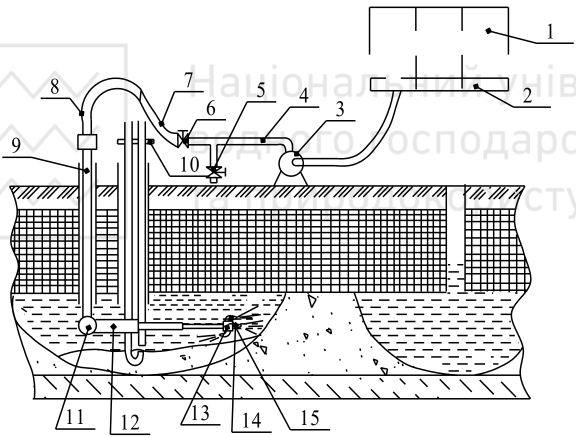

Fig. 1. Generalized technological scheme of hydraulic erosion and lifting of mineral: *1* - map of alluvium; *2* - sump; *3* - centrifugal pump; *4* - water pipe; *5* - reset latch; *6* - latch; *7* - flexible hose; *8* - upper swivel knee; *9* - vertical status of the hydromonitor; *10* - hydraulic 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 (hydro-monitoring, 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 widespread 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.

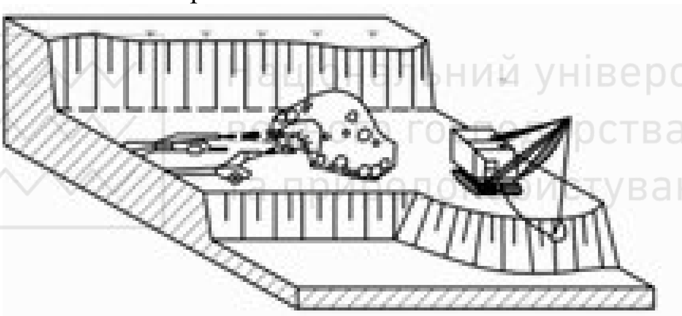

Fig. 2. Mechanical method of amber extraction

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.

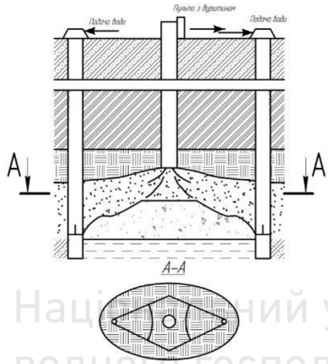

Fig. 3. Erosion of the next layered productive horizon

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].

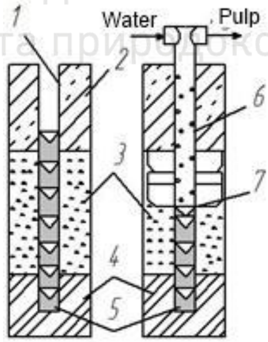

Fig. 4. The method of extraction of amber through wells

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.

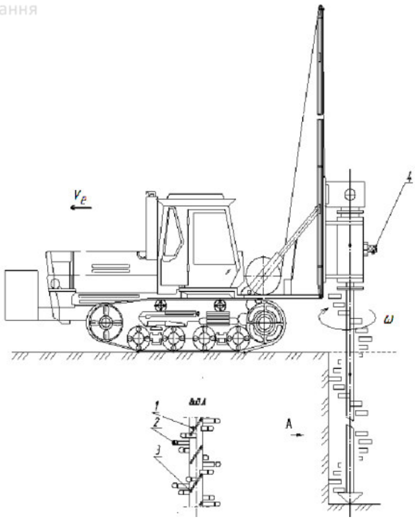

Fig. 5. The working body of the earthmoving machine for the extraction of minerals: *1* - hollow shaft; *2* - incisors; *3* - holes spaced in height; *4* - water supply hose

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.

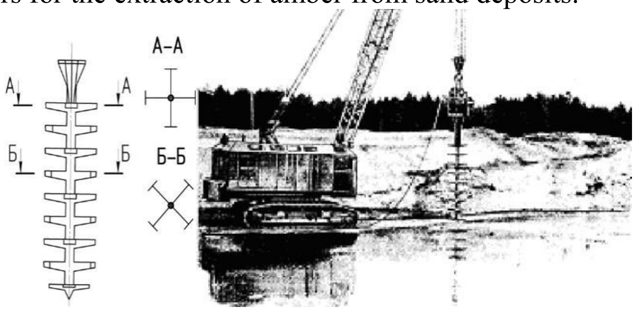

Fig. 6. Installation of VUUP-6

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.

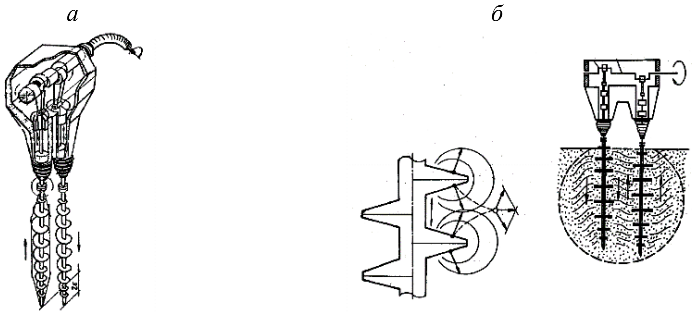

Fig. 7. Deep vibration compactor with screw vibration emitters

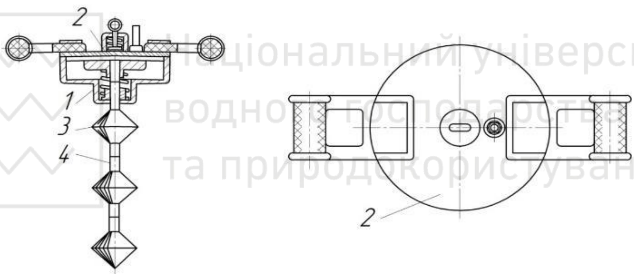

Fig. 8. Deep vibratory compactor with biconical vibratory emitters

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.

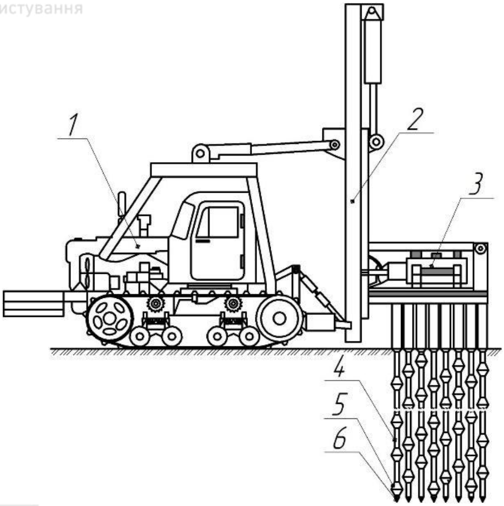

Fig. 9. Vibro-hydraulic intensifier with basic running equipment

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.

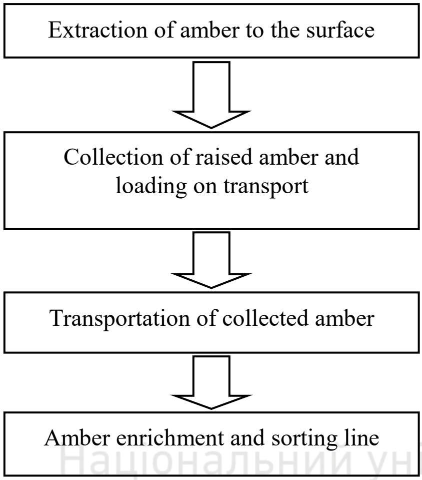

Fig. 10. Technological diagram of hydromechanical extraction of amber

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).

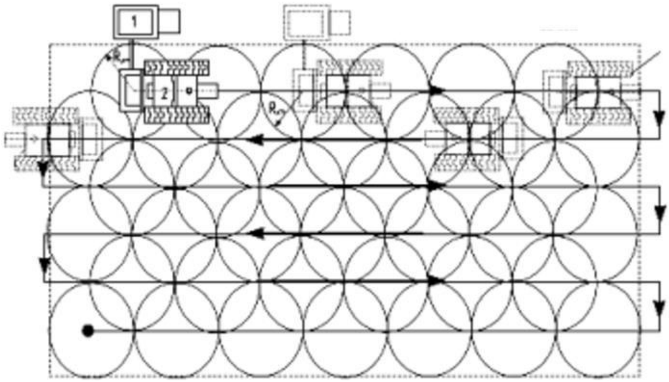

Fig. 11. Scheme of operation of the installation at the amber mining site

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.

References

1. **Malanchuk Z., Malanchuk E., Khrystyuk A.** Mathematical modeling of hydraulic mining from placer deposits of minerals / Mining of Mineral Deposits. National mining university, 2016. № 10. pp. 18-24.

2. **Malanchuk Z., Malanchuk E., Khrystyuk A.** Results of experimental studies of amber extraction by hydromechanical method in Ukraine / Eastern-European Journal of Enterprise Technologies, – 2016. Vol 3, №10(81). pp. 24–28. DOI: 10.15587/1729-4061.2016.72404

3. **Malanchuk Z.** Modeling the formation of high metal concentration zones in man-made deposits / **Malanchuk Z., Korniienko V., Malanchuk Ye., Soroka V., Vasylchuk O.** Mining of mineral deposits. ISSN 2415-3435, 2018, pp. 76-84 DOI: 10.15407/mining12.02.076.

4. **Malanchuk Z.** Results of experimental studies of amber extraction by hydromechanical method in Ukraine / **[Z. Malanchuk, V Korniyenko, Y. Malanchuk** and other.]. // EasternEuropean Journal of Enterprise Technologies. - 2016. - pp. 24–28. DOI: https://doi.org/10.15587/1729-4061.2016.72404.

5. **Malanchuk Z.** Examining features of the process of heavy metals distribution in technogenic placers at hydraulic mining / **Malanchuk Z., Malanchuk Ye., Korniyenko V., Ignatyuk I.** Eastern-European Journal of Enterprise Technologies ISSN 1729-3774, 2017, pp. 45-51 DOI:10.15587/1729-4061.2017.92638.

6. Arens V. (2001). Physical and chemical geotechnology: text-book (p. 656). Moscow: State. Mining University Press.

7. **Khrystyuk A. O.** Analiz isnuyuchykh sposobiv ta tekhnolohichnykh zasobiv hidromonitornoho rozmyvu / Visnyk Inzhenernoyi akademiyi nauk. Kyyiv, 2015. Vyp. № 1. C. 236–240.

8. **Malanchuk Z., Malanchuk E., Khrystyuk A.** Simulation of the comminution process to complex processing of metal-bearing basalt raw material / Cambridge Journal of Education and Science, 2015. No 2 (14), July-December. pp. 542–549.

9. **Malanchuk YE. Z., Khrystyuk A. O.** Matematychne modelyuvannya protsesiv sverdlovynnoho hidrovydobutku rozsypnykh korysnykh kopalyn / Visnyk Inzhenernoyi akademiyi nauk. Kyyiv, 2015. Vyp. № 4. C. 187-194.

10. **Khomenko O.Ye**. Principles of rock pressure energy usage during underground mining of deposits / **Khomenko, O.Ye., Sudakov, A.K., Malanchuk, Z.R., Malanchuk, Ye.Z.** / Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, National Mining University of Ukraine, ISBN: 2071-2227, 2017, pp 34-43.

11. **Malanchuk Z. R., Malanchuk E. Z., Korniyenko V. Ya.** Modern geotechnical methods of management of the process of amber extraction / Multi-authored monograph:"Innovative development of resource-saving technologies of mining of minerals" Publishsng house «St. Ivan Rilsky» Mining and Mining University of Geology (Sofia, Bulgaria). - 2018. - P. 80-103.

12. **Malanchuk Z.** Physico-Mechanical and Chemical Characteristics of Amber / [**Z. Malanchuk, V Moshynskyi, Y. Malanchuk** and other.]. // Solid State Phenomena. - 2018. - pp. 80-89. DOI: https://doi.org/10.4028/www.scientific.net/SSP.277.80.

13. **Naduty V.** Research results proving the dependence of the copper concentrate amount recovered from basalt raw material on the electric separator field intensity / **Naduty, V., Malanchuk, Z., Malanchuk, Y., Korniyenko, V.** / Eastern-European Journal of Enterprise Technologies ISSN 1729-3774, 2016, pp. 19-24 DOI: 10.15587/1729-4061.2016.79524.

14. **Malanchuk Z. R.** Results of studies on amber extraction by hydromechanical method / **Z. R. Malanchuk, V. Ya. Kornienko, E. Z. Malanchuk**. Mining of Mineral Deposits, 11(1), 2017, 93-99. DOI: http://doi.org/10.15407/mining11.01.093.

15. **Saik P.** Revisiting the underground gasification of coal reserves from contiguous seams / **P. B. Saik, R. O. Dychkovskyi, V. H. Lozynskyi, Z. R. Malanchuk, Ye. Z. Malanchuk**. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, №6, 2016, 60-66.

16. **Lozynskyi,V. G**. Experimental study of the influence of crossing the disjunctive geological fault on thermal regime of underground gasifier / **Lozynskyi,V. G., Dychkovskyi, R. O. , Falshtynskyi, V. S. , Saik, P. B., & Malanchuk, Ye. Z.,** Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2016, № 5. - p. 21-29.

17. **Malanchuk, E., Malanchuk, Z., Korniienko, V., Gromachenko, S.** The results of magnetic separation use in ore processing of metalliferous raw basalt of Volyn region. Mining of Mineral Deposits, 10(3), 2016, 77-83.

28. **Malanchyk Z., Korniyenko V.** Modern condition and prospects of extraction of amber in Ukraine / Proceedings of the 1st International Academic Congress "Fundamental and Applied Studies in the Pacific and Atlantic Oceans Countries". (Japan, Tokyo, 25 October 2014). Volume II. "Tokyo University Press". - 2014. - P. 318-321.

19. **Bulat A., Naduty V., Korniyenko V.** Substantiations of technological parameters of extraction of amber in Ukraine / American Journal of Scientific and Educational Research. - No.2. (5) (July-December). Volume II. "Columbia Press". - New York. - 2014. - P. 591-597.

20. **Bulat A., Naduty V., Korniyenko V.** Features spread occurrence of amber deposits in the world / Oxford Review of Education and Science. - №1 (9), January-June 2015. – P. 60–65.

21. **Bulat A, Nadutyi V, Kornienko V.** Modern technologies of amber extraction from sand deposits / Harvard Journal of Fundamental and Applied Studies, – No.1. (7) (January-June). Vol. VIII. "Harvard University Press". - 2015. - P. 514-519.

22. Promyslovi tekhnolohiyi vydobutku burshtynu. Monohrafiya / B**ulat A. F., Nadutyy V. P., Malanchuk YE. Z., Malanchuk Z. R., Korniyenko V. YA.** // - Dnipro–Rivne: IHTM–NUVHP. – 2017. – 237 c.

23. **Malanchuk Z. R., Malanchuk E. Z., Korniyenko V. Ya**. Modern geotechnical methods of management of the process of amber extraction / Multi-authored monograph:"Innovative development of resource-saving technologies of mining of minerals" Publishsng house «St. Ivan Rilsky» Mining and Mining University of Geology (Sofia, Bulgaria). - 2018. - P. 80-103.

24. **Ye. Malanchuk, V. Korniienko, V. Moshynskyi, V. Soroka, A. Khrystyuk, Z. Malanchuk** Regularities of hydromechanical amber extraction from sandy deposits MINING OF MINERAL DEPOSITS, - 2019. Volume: 13 Issue: 1 Pages: 49-57.