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FEASIBILITY OF TYPE OF DEEP-WATER TECHNOLOGIES FOR THE EXTRACTION OF MARINE FERRO-MANGANESE NODULES

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The conditions for the occurrence of near bottom minerals presented in the form of sulphides (the Logachev deposit) and ferro-manganese nodules (The conditions for the occurrence of benthic minerals presented in the form of sulphides (the Logachev deposit) and ferro-manganese nodules (FMN) are considered. An analysis of the structures and parameters of various means of collecting and transporting sulphides and iron ore from the bottom to the surface is given, and the possibility of effectively using vessel lifting on a cable-rope is indicated. Structural schemes for collecting FMN and sulphides in the form of containers on a cable, equipped with manipulators with gripping devices of a disc, drum or clamshell type, are proposed. In them, the capture of rock pieces or FMN is carried out by creating a vacuum in the collectors of the executive bodies and attracting to them pieces of rock or FMN by a pressure drop of water inside and outside the reservoir. It was given the approximate parameters of the mining system. So, for a cable-rope made of kevlar with a diameter of 50 mm, the capacity can be 200-400 thousand tons per year for one installation with different specific mass concentration of FMN per 1 m^2) are considered.
***Key words*:** World ocean; ferro-manganese nodules; sulfides; cable-rope; bottom mining complex; performance

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Introduction. Modern studies of both geophysical and sampling methods have proved that on the bed of the World Ocean (depth from 1.5 to 5 km) there are three types of bottom deep-sea minerals of interest: ferro-manganese nodules (FMN), cobalt-manganese crusts (CMC) and sulfides. All these are unique fields, the industrial development of which is not conducted at present.

From the point of view of mining from the ocean floor, the greatest interest (unfortunately, and technical difficulty) is mining of FMN, which are mostly spherical formations with a diameter of 5-20 cm. They lie evenly on the bottom surface, sometimes slightly immersed in silt.

The particular difficulty of creating deep-water equipment is caused by the very difficult operating conditions of machines at a depth of 5 km of the ocean: water pressure 50 MPa, temperature 2-3 °C, locally located acid inclusions or areas of water with high salt content, underwater currents, etc. Nevertheless, various methods of industrial mining of these various types of bottom minerals can be proposed [1-3, 5-8]. The following can be singled out among them (Fig.1 [8]): mechanical raking; hydraulic capture and transportation; open pit mining (quarries) on bottom mining for mining FMN and CMC. At the same time, devices similar to machines that work in quarries are needed.

Methods and means of mining from the bottom of the World ocean. The greatest difficulty is the rise of the material from the bottom to the surface. The analysis of patents shows that the most often proposed method of vertical transportation – the use of hydro transport. Thus, Nautilus Minerals (an international consortium) has developed a technology in which pipes should not break under their own weight, and mining machines work out the material while simultaneously ensuring bottom crushing of mineral resources to a pipe size of not more than 5 cm.

Air-lift units can also be used when compressed air is fed into the pipe at a certain depth (usually less than 1.5 km). It is also proposed lifting minerals in vessels. The device can be developed as a kind of submarine, which independently sinks to the bottom, then, reducing its weight and seizing minerals, rises from the bottom to the surface (they can be used only in depths up to 1 km).

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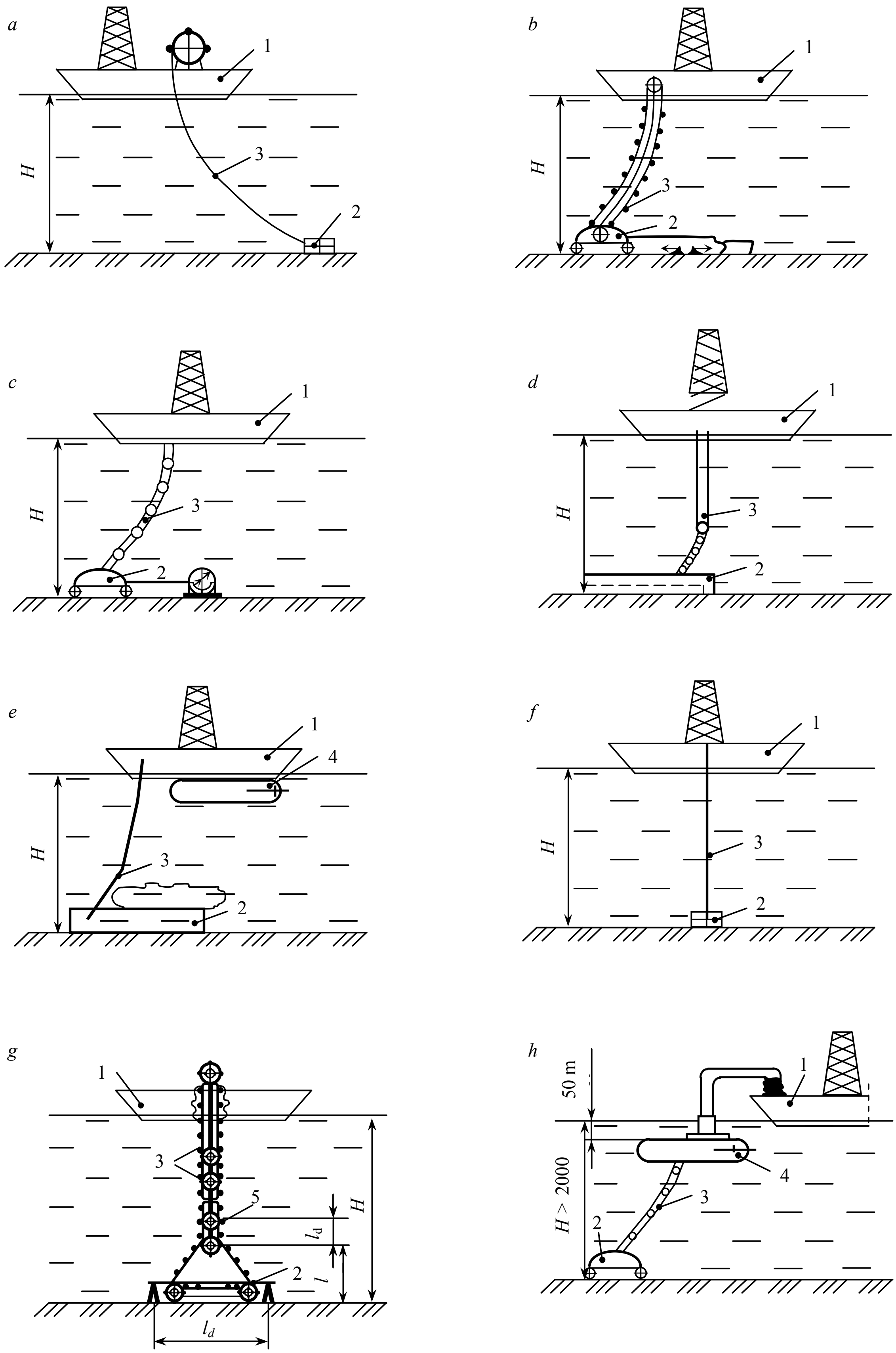

Fig.1. Simplified layout of deep-sea mining units: *a* – rope scraper (winch on board); *b* – bucket elevator; *c* – hydrotransport; *d* – airlift; *e* – self-exploring installation; *f* – container lift; *g* – bucket belt with intermediate drives; *h* – hydrotransport with submersible (50-100 m) capsule with pumps

1 – carrier ship; 2 – bottom unit; 3 – vehicle; 4 – autonomous pop-up unit; 5 – intermediate drive

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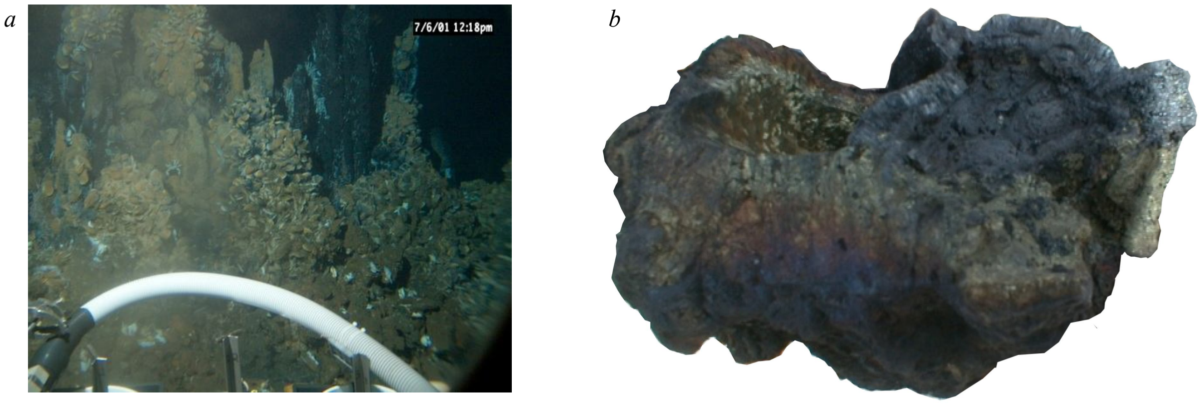

Fig.2. Deepwater sulphide deposit: *a* – general view; *b* – «smoker» sample

In our opinion, the use of a winch installed on a ship and a cable-rope is of the greatest interest. It is obvious that the steel ropes are not applicable. Calculations show that when using cable-ropes with a diameter of 6 cm, the outer carrying braid of which is made of kevlar (made in Germany or China), the maximum tractive force, taking into account the weight of the rope (not more than 10 tons) and the dynamics of work, is 150 tons. Dynamic the component at the beginning of the movement of the installation from the bottom in the water column is 20 tons (the frontal section of the vessel is 10 m^2, the speed is 3 m/s). Thus, it turns out that the vessel (skip) allows you to lift up to 80 tons of minerals per cycle. The minimum cycle time, which consists of the time of lifting and lowering, loading and unloading on the surface, is about 2 hours. As the calculations showed, for the above parameters, the performance of a special vessel with special devices can be 200-400 thousand tons of minerals year. All this suggests the profitability of the method.

According to prof. S.M.Sudarikov, who personally investigated deepwater «Logachev» sulphide deposits on deep-water apparatuses, the so-called «smokers» initially represent the pillars of formations, inside which are strong tubular sulphides, mainly of iron and copper. Oxidized on the surface, they are loose rocks with a lower strength (Fig.2).

These pillars, «smokers», are destroyed over time and form oxidized sulfides at the bottom of the deposit in the form of a very uneven relief.

Testing pillars especially active «smokers» is impractical because of the high temperature (350 °C) and high acidity. In addition, given the method of separation from the array of pieces and their rise to the surface, such works cause serious technical difficulties, and often are simply impossible. Therefore, mining operations can be carried out only on the cooled and collapsed pillars of «smokers», but even in this case, the use of traditional technologies similar to open-cast mining on the surface of the earth is very difficult – the quarry uses the drilling and blasting method. It is necessary to align the sites for the equipment, and for strong rocks such work at great depths requires serious research and experimental studies.

Thus, the technology mastered by the concern «Nautilus Minerals» can be applied for complex bottom reliefs of strong sulphides. However, the real work of the complex of tires proposed by this concern is associated with the solution of a large number of very serious problems.

To collect an FMN in an environmentally «clean» way, we propose a technology in which nodules are collected by a device equipped with manipulators with plates that capture FMNs by creating a vacuum in the cavities of these plates (vacuum grippers (VG)). Such a device for collecting heavy ferromanganese nodules, currently patented (Fig.3), relates to mining, in particular, to devices for underwater mining of mineral resources.

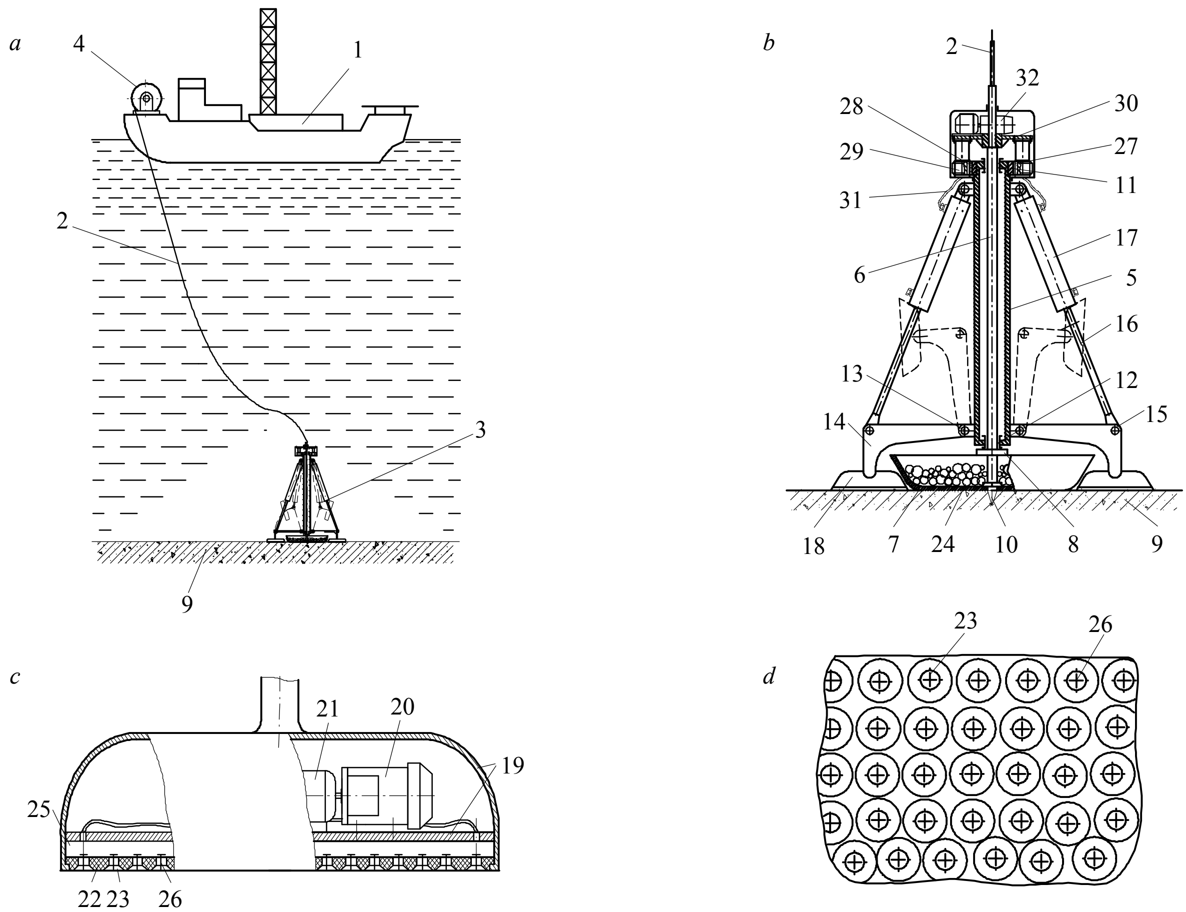

Fig.3. Scheme of the device for collecting heavy iron-manganese nodules: *a* – a complex for collecting TFA; *b* – a general view of the bottom mining device; *c* – general view of the vacuum capture; *g* – bottom view on vacuum capture

1 – watercraft; 2 – cable; 3 – bottom mining device; 4 – winch; 5 – central pin; 6 – stand; 7 – receiving hopper; 8 – supporting collar; 9 – surface of the seabed; 10 – the tip of the rack; 11, 12 – bearings; 13 – the hinge; 14 – L-shaped lever; 15 – the top of the L-shaped lever; 16 – hydraulic cylinder rod; 17 – hydraulic cylinder; 18 – vacuum capture; 19 – the case; 20 – electric motor; 21 – pump; 22 – elastic plate; 23 – tapered bore; 24 – ferromanganese nodule; 25 – clearance; 26 – check valve; 27 – rotation mechanism; 28 – a gear wreath; 29 – drive gear; 30 – support; 31 – pipe; 32 – drive station

Known FMN mining mechanism, equipped with a surface watercraft, transporting body, bottom mining device collection with a hopper for filling buckets, mounted on the traction rope. The mining device is installed on a sled, equipped with a knife-ripper in the front part, has a bottom in the form of a screen mesh, moves with the help of a rope. The movement of the mining device on the bottom and scoops on the rope is controlled from the surface of the vessel.

The disadvantages of the mechanism are low productivity, which directly depends on the width of the buckets, and the enrichment factor of the nodules on the bottom, which leads to the lifting of a large amount of waste rock, entanglement of the branches of the traction rope due to their free sagging, disruption of the ecological situation in the process of lifting the filled buckets.

The device for the extraction of nodules from the sea shelf contains a surface floating craft with equipment installed on it to ensure the operation of the device transporting the bucket circuits, the towing rope, the bottom mining device in the form of one and a half, mounted on a skid.

The disadvantage of this device is a significant loss of mineral during transportation due to the free hanging of the branches of the transporting circuit.

The installation for the extraction of minerals from the bottom of the water area includes a surface floating craft with the necessary equipment for maintaining the life support and operation of the personnel and means of power supply and control of the complex, a hydraulic lift pipeline, a bottom-mounted tracked vehicle with a drum executive unit.

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The disadvantages of this installation are the difficult control of the bottom mechanism, associated with increased turbidity of the environment during operation of the track chain, limited system performance due to the need to reduce the diameter of the pipelines when working at great depths, and the possibility of pipe shrinking.

The device for selective selection and preliminary enrichment of ferromanganese nodules [3], adopted for the prototype, includes a surface watercraft, a transporting body, a bottom mining device in the form of a drum with longitudinal grooves on the outer surface.

The disadvantage of this device is the impossibility of mining at great depths, low installation performance due to the limited width of the drum, high turbidity in the area of work.

The technical result of the use of the mining complex with the VG is the elimination of these shortcomings, namely ensuring the production of ferromanganese nodules at considerable depths (up to 5000 m), eliminating turbidity in the mining zone and increasing the productivity of the installation. The technical result of using the complex with VG can be obtained if the transporting body is made in the form of a cable, and the bottom mining device includes a receiving hopper in the shape of a truncated cone rigidly connected with a stand located inside the central trunnion, the lower part of which is pivotally connected to two L-shaped levers, at the ends of which are located vacuum grips of ferromanganese nodules, and the upper part is pivotally connected to the tops of the L-shaped levers by means of hydraulic cylinders and is equipped with gear ring, which engages with two drive gears mounted on the rack, while the rack is rigidly connected to the carrier part of the cable.

Diagram of the device for collecting heavy ferromanganese nodules is shown in Fig.3. A device for collecting ferromanganese nodules, or a complex with a VG (Fig.3, a), includes a surface floating craft, a cable-rope, and a bottom mining device. The cable is connected to a lifting winch installed on the watercraft.

The bottom mining device (Fig.3, *b*) contains a central pin, inside of which there is a rack rigidly connected with the receiving bunker. The rack is made with a support collar, on which the trunnion rests. For reliable fixation of the bunker on the surface of the seabed, the end of the rack in the form of a tip is inserted into the bottom surface when lowering the bottom mining device.

The trunnion rests on the shoulder of the rack and is movably connected with it by bearings for rotation to the axis of the rack. The lower part of the central pin is connected to hinges with two L-shaped levers located diametrically relative to each other. The tops of the L-shaped levers are pivotally connected to the rods of the hydraulic cylinders attached to the top of the trunnion.

At the ends of the L-shaped levers are fixed vacuum seizures of ferromanganese nodules. In the case (Fig.3, *c*) of a vacuum gripper, an electric motor is placed in an oil bath and a pump.

The base of the vacuum grip is made in the form of a replaceable elastic plate, on the surface of which the through conical holes are uniformly distributed (Fig.3, *d*), the size of which depends on the diameter of the mined ferromanganese nodules, obtained on the basis of geological exploration of the bottom space.

Between the elastic plate and the body there is a gap (Fig.3, *c*) whose width is selected depending on the elasticity of the plate. Cone holes are provided with non-return valves locking the holes in the absence of nodules.

To rotate the vacuum grippers to the axis of the rack in order to change their position around the receiving bin, inside the central pin there is a rotation mechanism with a toothed rim that meshes with the drive gears on a support rigidly mounted on the rack.

The cylinders are connected to a drive station, also mounted on a support, using a network of connections. The rack is connected to the supporting cable-rope associated with the winch boats.

The proposed device for collecting heavy ferromanganese nodules works as follows. The bottom mining device from the watercraft is lowered to the bottom area with the help of a cable-rope. The device is supported on the bottom by a bunker, while the tip of the stand is embedded in the surface of the seabed and reliably fixes the position of the bunker. L-shaped levers with vacuum grippers occupy the upper (transport) position (dotted line, Fig.3, *b*). When pressure is applied from the drive station to the piston zone of the hydraulic cylinders, the rods are pushed in and the L-shaped levers rotate to the center of the hinges until the vacuum grips touch the bottom surface. Next, the electric motors that are powered by cable-rope, include pumps vacuum seizures. Water from the tapered holes of the elastic plate along the longitudinal gaps is pumped out by the pump, as a result of which a vacuum occurs over the entire surface of the grip in the zone of the tapered holes. Due to rarefaction, the capture and retention of ferromanganese nodules on the surface of the elastic plate occurs. If there is no nodule in any of the taper holes, the check valve remains closed.

After the nodules are seized by vacuum grippers, the hydraulic cylinders turn the L-shaped levers with vacuum grips to a convenient position for unloading. As soon as the vacuum grippers are above the surface of the receiving bunker, the pumps and heavy ferromanganese nodules are turned off under the action of their own weight fall into the receiving bunker. Then they turn on the turning mechanism and turn the central trunnion together with the L-shaped levers fixed on it with vacuum grippers and hydraulic cylinders to a certain angle corresponding to the new position of the grips.

As soon as the area around the receiving bunker is fully processed and the bunker is completely filled, the bottom mining device is lifted onto the surface floating craft with the help of a cable.

Mined ferromanganese nodules lifted on a boat are stored in shakes and then transported by barges to the shore for further processing.

Thus, the proposed device makes it possible to ensure the extraction of ferromanganese nodules at considerable depths (up to 5000 m), to increase plant productivity by eliminating multiple tripping operations, since the nodules are previously accumulated in the receiving bunker until it is completely filled, while the sea bottom is not disturbed when seizure of nodules, which eliminates turbidity in the zone of mining deposits.

Laboratory model research of the bottom mining device. The study of the model of the bottom mining device on the basis of a capture device with vacuum cavities (or vacuum grippers – VG) was carried out on the stand (Fig.4) [8-12]. The process of capturing and holding imitation FMN occurred with a loose attraction of objects and constant flow of water.

The main objective of the experiment is to determine the likelihood of capturing a FMN depending on the time of direct contact with the collecting device. The probability of capture was calculated from the ratio of the number of captured objects to the total number of the maximum possible capture. The pump capacity was 0.125 l/s. The result of the experiment on capturing imitations of the FMN is presented in Fig.5.

It can be seen from the graph that with an increase in the contact time of a gripping device with nodules, the probability of their capture increases, but too long contact time will inevitably lead to a decrease in the velocity of movement of the bottom mining device, and as a result – to a reduction in the overall productivity of the mining unit.

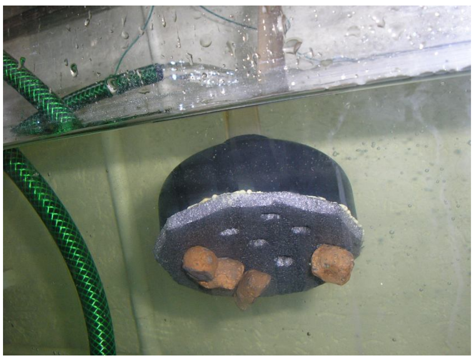

Fig.4. Capture nodule imitation objects

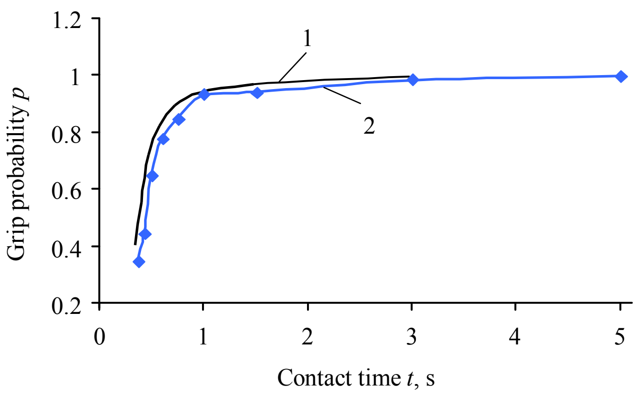

Fig.5. Dependence of the probability of capturing an imitation of nodules on the time of contact with the device
1 – approximating curve; 2 – experimental data

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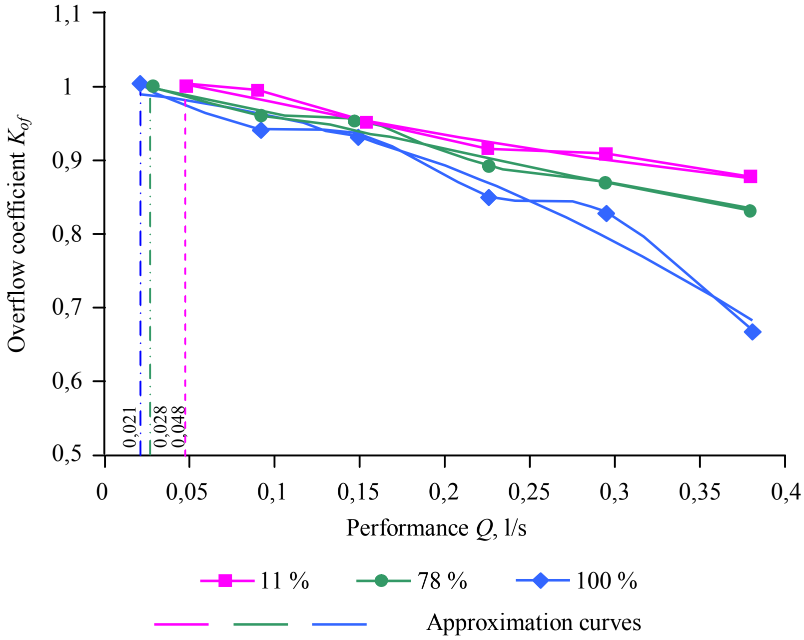

Fig.6. Dependence of the overflow coefficient on the pump performance

The study of the process of seizing FMN is reflected in the graph of the dependence of the coefficient of flow on the pump performance at different values of the percentage use of the working space of the gripping device (Fig.6). Stable capture and retention of nodules are observed when the overflow rate is less than one. It can be seen from the graph that the decrease in the overflow coefficient with increasing pump performance and 100 % utilization of the working space of the capture occurs with greater intensity than in other cases, which provides a more stable capture with the same performance value. In addition, the critical value of the pump performance, at which the nodules detach from the capture device at 100 % use of the working space, is minimal.

Effective performance of the VG is observed when the value of the coefficient of overflow $K_{of} < 1$, and a stable retention of the captured nodules at K_{of} = 0-0.55 and with maximum use of the working space of the capture device.

Conclusion. For now, the following problems remain unresolved: the technology of processing of FMN and CMC for the production of metals is still not completely clear; there is not enough time to develop and create pilot mining deep-water installations (3-5 years). According to international requirements, if you do not proceed to the pilot production of these fields, these sites will be put up for auction and can be bought by other countries; all devices that operate in the bottom zone must pass an environmental assessment in an international independent organization. However, the devices developed at the department of machine building at Saint-Petersburg Mining University and tested in laboratory conditions, capturing the FMN using plates in which a vacuum is created followed by overloading in tanks, suggest that such devices are combined with kevlar cables and special ship installations provide an original solution to the problem of the experimental industrial collection of FMNs in the World ocean.

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