Mathematical model of device for slurry concentration and desludging in near-bottom zone

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Abstract. There are many systems for extracting minerals from the bottom of water bodies, but none of them meets the requirements, so the actual task is to create technical means that provide the best performance and environmental safety. Increase the efficiency of the hydromechanical mining method is possible due to the maximum concentration and desludging of the slurry in the near-bottom zone, which allows reducing the energy and material consumption of hydrotransport of minerals. To achieve this goal, it is proposed to use a perforated section adjacent to the power unit, with a transverse cross section that reduces in its length in the direction of flow, in the pressure pulp pipeline system.

1. Introduction.
A hydromechanical method [1-4] of mineral extraction is more productive than the system with the use of mechanical capture means that allows developing an underwater deposit better and fuller. Essential disadvantages of this method are: high energy consumption because of the large pulp dilution due to unavoidable suction of water into the receiving device of the power plant; significant ponderosity and metal consumption of the pipeline system with a large diameter of the flexible slurry pipeline; complex and costly pipeline management system; the need to return a significant amount of sludge obtained as a result of separation and dehydration of the rock mass on board the base vessel to the sea bottom through a special pipeline.

The technical and economic parameters of the hydromechanical method of mining can be significantly improved with the maximum slurry concentration and desludging directly in the bottom zone. When solving this problem, the method of mechanized mineral extraction may prove to be quite competitive with an alternative method based on mechanical capture of nodules.

2. Method of mineral extraction from the seabed along with slurry concentration and desludging in near-bottom zone.
It is possible to achieve the necessary degree of the slurry concentration with its release from a significant part of the sludge component and non-commodity fractions of nodules, in the following way (Figure 1).
A device for mining minerals [5] from the seabed includes a base vessel, a mobile bottom-end unit with a take-up device and a power plant, a pressure pipeline adjacent to the mobile unit; the section of the pressure pipeline must be equipped with a device for slurry concentration and desludging, made in the form of a perforated joint with a variable along its length cross-sectional area, and with a decrease in this area away from the mobile unit. The size of the holes of the joint perforated part is accepted according to the grain-size classification. The holes size should be less than the minimum size of mined nodules.

When dredging pump of a power plant is operating, the slurry, which is largely watered and contaminated with clayey and muddy bottom sediments, comes to the perforated section of the slurry pipeline under pressure slightly higher than the pressure necessary to transport the slurry to the base vessel. Excess water along with the mud component and small off grade fractions are removed through the holes in this section of the slurry pipeline due to overflow pressure. Slurry with a specified (optimal) volume concentration of the solid component is transported along the main section of the slurry pipeline of smaller diameter. At the same time, the slurry is significantly enriched by separating the bulk of the sludge and off grade fractions from it.

Advantages of the new system for hydromechanization of mining from the seabed are: 1) the water content and the corresponding flow rate of the slurry at the main section of the slurry pipeline from the power unit to the base vessel decreases by a predetermined number of times; 2) the diameter of the slurry pipeline decreases respectively; 3) the energy consumption of the slurry transport and the installed power of the dredging pump drive are reduced almost in the same ratio as a decrease in the flow rate of the slurry; 4) the mass of the entire system for the extraction and transportation of the slurry is significantly reduced; 5) the system for managing the processes of the slurry extraction and transportation to the base vessel is simplified; 6) environmental safety in the development of deposits increases due to a significant reduction in the level of the water area pollution (especially on its surface) by bottom sediments.

These advantages are achieved by a relatively small increase in the operating pressure produced by the dredging pump.

3. The mathematical model of the device for slurry concentration and desludging.
The main parameters of the device [6] for the slurry concentration and desludging (Figure 2) are determined in the following order:

1. The mass productivity (t/h) is set by the nodule.
2. The volumetric productivity $V_s$ (m$^3$/h) for nodules is calculated.
3. The volume concentration ($S$) of the slurry is determined in the main section of the slurry line, along which the calculated density of the slurry is determined (kg/m$^3$).
4. The water flow rate (m$^3$/h) in the main section of the slurry pipeline is determined.
5. The total flow rate of the slurry (m$^3$/h) in the main section of the slurry pipeline is determined.
6. Based on empirical (industrial) or experimental data obtained in laboratory studies, the values of the volumetric concentration ($S'_0$) captured by a ground pump from an underwater face are taken.
7. The estimated pumping capacity \( V_1 \) \( (m^3/h) \) (flow rate) of the slurry, captured by the dredging pump, is determined.

8. According to the calculated \( V_1 \), the type and model of the dredging pump are selected in compliance with the specific conditions for the nodules extraction (sea depth, required head). In accordance with the performance of the selected dredging pump, its pumping capacity \( V_1 \) and volume concentration \( S_0 \) is specified.

9. The initial \( D_1 \) and the final \( D_2 \) diameters (m) of the slurry line perforated section are determined as a function of the calculated velocity \( v \) (m/s) of the slurry motion (according to the usual method) and the ratio of slurry flow rates at the beginning \( (V_1) \) and end \( (V_2) \) of the perforated section of the slurry pipeline under the assumption that the speed of the slurry is constant along the length of the slurry line.

The minimum diameter \( (D_2) \) of the slurry line is checked for the maximum size \( d_{\text{max}} \) of the nodules.

10. The maximum of the two values obtained \( D_2 \) and \( D_2^\text{th} \) is chosen, it should correspond to the standard diameter of pipes produced by enterprises.

11. The flow of water with sludge discharged on the perforated section of the slurry pipeline is determined.

12. On the basis of the grain-size composition of mined nodules, the minimum (commercial) fineness \( (d_{\text{min}}, m) \) of nodules is selected, according to which the slurry distribution should occur in the near-bottom zone.

13. The diameter \( (d, m) \) of the holes in the perforated section of the slurry pipeline and their spacing \( (a, m) \) in the axial direction and along the perimeter of the slurry pipeline are assigned.

14. The velocity of water flow \( (C, m/s) \) with slime particles (with particles less than \( d \)) through the holes in the perforated part of the slurry pipeline is determined.

15. The length \( (l, m) \) of the perforated section of the slurry pipeline is determined by the following considerations.

Total square area \( (m^2) \) of holes along the perimeter of the perforated section of the slurry pipeline at its removal \( x \) (m) from the head section (see Figure 2) is:

\[
F(x) = \frac{\pi d^2}{4} \cdot \frac{\pi D}{a} = \frac{\pi^2 d^2}{4a} \left[ D_2 + \frac{D_1 - D_2}{l} (l - x) \right],
\]

where \( D \) is the diameter (internal) of the perforated section of the slurry pipeline at a distance \( x \) from the head section, m.

The number of rows of holes along the length of the perforated section is \( m = l / a \).

The total area of the holes at the elementary length \( dx \) of the perforated section of the slurry pipeline is:
The length of the perforated section of the slurry pipeline is related with other parameters by the following differential equation:

\[ dF(x) = \frac{mF(x)}{l} \frac{dx}{a} = \frac{F(x)}{a} dx. \]  

(2)

The length of the perforated section of the slurry pipeline is related with other parameters by the following integral equation:

\[ V = C \int_0^l \left[ \frac{D_1 - D_2}{l} \left( l - x \right) \right] dx = C \frac{\pi^2 d^2}{8a^2} (D_1 + D_2) l, \]

wherefrom

\[ l = \frac{8V_S (S - S_0) \lambda^2}{\pi^2 SS_0 (D_1 + D_2) C} = \frac{8V_S (S - S_0) \lambda^2}{\pi^2 SS_0 (D_1 + D_2) \mu \sqrt{2(\frac{P_H - gH}{\gamma_0})}}, \]

(3)

where \( \lambda = a / d \), \( \mu \) – jet contraction coefficient, \( \mu = \sqrt{\frac{1}{\xi}} \), \( \xi \) – coefficient, depending on the Reynolds number and the shape of the hole; \( P_H \) – pressure generated by the dredging pump, Pa; \( H \) – depth of the water body, m; \( g \) – acceleration of gravity, m/s\(^2\), \( \gamma_0 \) – density of working fluid (water), kg/m\(^3\).

4. Conclusion.

Analysis of functional relationships between the parameters of the device and the results of the performed calculations makes it possible to draw the following conclusions:

1. The volume of excess water and sludges removed from the slurry with a uniform distribution of holes on the conic surface of the perforated section of the slurry line is proportional to the ratio of the squares of the pipeline diameters in its head and tail sections and the length of the perforated section of the slurry pipeline.

2. The average intensity of water-sludge separation rises with the increase in pressure head created by the dredging pump, along the saturation curve.

3. The length of the perforated section of the slurry pipeline at a predetermined value of the pressure head is directly proportional to the volume of excess water and sludges removed from the slurry.

4. The required length of the slurry pipeline perforated section at a given value of the water-sludge separation with an increase in the pressure head of the dredging pump decreases sharply along the inverted saturation curve.

5. The required length of the perforated section of the slurry pipeline with the given values of water-sludge separation and the dredging pump head gradually rises with the increase of ratio of the holes spacing and their diameter on the conical surface.

6. The use of a device for concentration and desludging the slurry directly in the near-bottom zone while maintaining the same mass productivity with nodules makes it possible to ensure:

- a twofold decrease in the volume of the pumped slurry, the installed power of the power unit, the energy consumption, the metal consumption of the entire complex for capturing and transporting nodules to the side of the base vessel;
- a reduction of the sludge content by more than two times in the base vessel of the slurry delivered on board;
- a reduction of the slurry pipeline diameter by 30%;
- a simpler, more reliable and less costly system for controlling the movement of the power unit during mine field development;
- a reduction of the resulted expenses by 48-49% depending on the installed capacity of the dredging pump.
References
[1] Serpukhov V I, Ivanov A I 1978 Autigenno-diagenicheskiye i organogennyye obrazovaniya morey i okeanov (Leningrad: Leningrad Mining Institute) p 48
[2] Makhovikov B S 1997 Mining journal 11
[3] Dobretsov V B, Kuleshov A A 2001 Mining journal 8
[4] Matousek V 2004 Dredge pumps and slurry transport Lect notes Delft U T (Delft University of Technology)
[5] Tarasov Yu D 2003 Russian Federation patent no. 2219342, publ. 20.12.2003.
[6] Tarasov Yu D, Shishkin P V 2004 Russian Federation patent no. 2228441, publ. 10.05.2004.