SOME RESULTS OF EXPERIMENTAL STUDIES OF THE MAIN PARAMETERS OF THE CAPSULES HYDRAULIC TRANSPORT IN VERTICAL PIPELINE IN RELATION TO THE PROBLEMS OF LIFTING THE NODULES FROM THE SEABED AND OCEAN FLOOR

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Abstract. The paper presents some results of experimental studies of the main parameters of the capsules hydrotransport in vertical pipelines. Measurements of specific hydraulic resistances and average velocity of capsules for various flow regimes were carried out in a series of large-scale laboratory installations. The experiments were carried out not only in the vertical, but also in the inclined (ascending and descending) sections of the pipeline. The results can be used to develop relevant hydrodynamic calculation methods for designing the pilot and industrial capsule pipeline systems which are intended to lift nodules from the seabed and ocean floor.

Keywords: capsules hydrotransport, hydraulic resistance, pipeline stand, seabed nodules.

1. INTRODUCTION

In recent years, the practical interest in the issue of extraction, transportation and use of various new mineral deposits has increased significantly. At the same time, close attention of specialists is paid to a relatively new problem – the development of the shelf, as one of the new, but rather promising sources of raw materials for the metallurgical industry. As a rule, the bulk of various valuable elements are contained in nodules, which can be located at a distance of several kilometers on the bottom of the seas and ocean.

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The available world experience in the processing of nodules from various regions shows sufficient efficiency and prospects for obtaining on the basis of this technology, first of all, components of a number of metal ores.

In the general problem of shelf development, one of the most important is the problem of the direct rise of nodules from the bottom of the seas or ocean. According to a number of experts, one of the most realistic ways of lifting these nodules is the use of the vertical capsules pipeline hydrotransport (CPT) systems.

It should be noted here, that nodules are rather fragile, lumpy materials of irregular shape, which average diameter may exceed 50 mm. This fact is another circumstance that makes it possible to recommend using the hydraulic capsule pipeline systems for transportation of such fragile dispersed and lumpy materials.

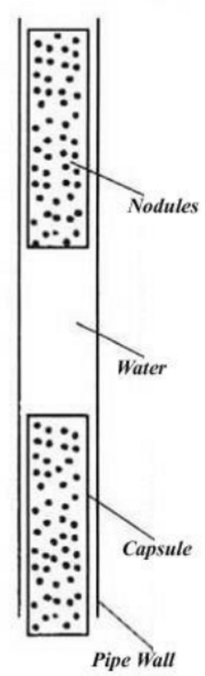


Fig. 1. Schematic view of the capsule vertical pipeline hydrotransport of nodules

As it is known, with CPT the transported material (in our case, nodules) is loaded into capsules (containers) and vertically moves through pipes together with the flow of liquid (water of a given equator). The capsules can be either rigid or reusable mesh shell. As a rule, the most appropriate for use are the capsules of cylindrical shape. Without dwelling here in detail on purely technical issues of loading and unloading capsules with nodules, we will discuss only the linear lifting part of this kind of the pressure head vertical capsule system. The schematic diagram of this linear part of the CPT is shown in Fig. 1.

2. EXPERIMENTAL SETUP

In view of the complexity of modeling the flows under consideration, it is advisable to carry out such experimental studies of a pressure head vertical CPT on a series of large-scale installations in a wide range of variable conditions of hydrotransportation.

Some results of these joint studies carried out at the experimental stands of the Institute of Hydromechanics of the National Academy of Sciences of Ukraine (IHM NASU) are presented in this paper.

The Institute of Hydromechanics of the National Academy of Sciences of Ukraine has multiyear experience of joint research in the field of pipeline hydrotransport of capsules in straight, bend and inclined (including vertical) pipeline sections. The Institute has at its disposal a series of large-scale installations for studying the main dynamic and kinematic parameters of capsule flows in various sections of the pipeline. For the above reasons, IHM NASU was involved in an international research project aiming at the study of possible use of the capsules pipeline hydrotransport systems for lifting nodules from the bottom of the seas and ocean.

For detailed study of the vertical hydrotransport of capsules, two existing experimental stands in the IHM NASU were modified to enable the parameters' study of the hydrotransport of spherical and cylindrical capsules. At the same time, the diameter of the working area at the first vertical stand was variable and amounted to 12, 20 or 25 mm.

In addition, another stand was used for transportation of capsules of various size and density. It was a direct-flow unit with a U-shaped pipeline with diameter of $D = 29$ mm. This stand was mounted in such a way that to enable adjusting the angle of inclination of the pipeline from 0 to 90 degrees.

Structurally, the experimental stand with a removable vertical section (Fig. 2) is a direct-flow hydrodynamic device of periodic (cyclic) action. In general, the stand consisted of the following main units: loading unit for capsules (1), pressure tank (2), transport pipeline, working section (8) with transparent inserts (6), pressure taps (7), pump (3), filter (5) and receiving tank (drain tank) (4).

The capsules dispenser was made in the form of an open top container with a neck in its lower part, into which washer 9 with different inner diameters was inserted, that made it possible to set specific flow velocity of capsules according to the preliminary calibration data.

The pressure vessel 2 made using the Mariotte bottle effect differed from the standard Mariotte bottle, so as a cylindrical pipe was installed along its axis, serving to supply the solid phase (capsules).

The experimental stand was equipped with all the necessary instruments and devices that allowed one to simultaneously determine such transportation parameters as hydraulic resistance, as well as the average velocity of flow and capsules.

In studies on the above stand, spherical and cylindrical bodies (capsules) with density $\rho_s = 2000$ kg/m^3 were used. Such density, taking into account the bulk density, is quite close to the density of real nodules.

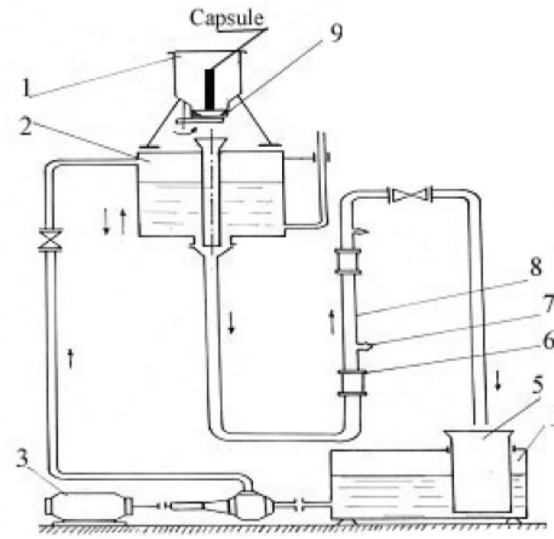


Fig. 2. Schematic view of the experimental stand

The scheme of the U-shaped pipeline stand with inner diameter of $D = 29$ mm is shown in Fig. 3. On this stand it was possible to change the angle of inclination of the pipeline α from 0 to 90 degrees. The stand comprised the following elements: pump (6) with suction (5) and discharge (7) pipelines, sump (13), transport pipeline (14), loading device (2), receiving tank (16), and electric winch (10).

The pressure pipeline (7) had two branches. Venturi pipes (8) and control valves (9) were installed on each of them. As for the loading device (2), then in this device between the tee (4) and the flexible hose (2) a special cork faucet (3) was installed, allowing the capsules to pass in the open position. The use of the faucet was caused by a relatively high pressure (up to 4 atm.) at the inlet of the transport pipeline. Loading of capsules was carried out with a closed cork faucet.

The transport pipeline (12) consisted of two straight sections of 5 m length, made of steel pipes with diameter of 29 mm, as well as two bends with angles $\alpha = 90^\circ$ and one with angle $\alpha = 180^\circ$. The curvature radius of the bends equaled $R = 1$ m. The bends were made of polyethylene pipes with an inner diameter of 31 mm connected to metal pipes using steel diffusion and converging inserts and flanges.

The entire transport pipeline was fixed on a steel frame, which could rotate relative to the slewing bearings (1). Such design enabled adjusting the angle of inclination of the frame without twisting the pipeline. The frame was lifted to the required angle by an electric winch (10).

To study the main parameters of the hydrotransport of the capsules, on each of the straight sections of the transport pipeline with measuring section of 3 m long, the pressure tapping was equipped. Transparent inserts (11) were installed at the beginning and the end of the measuring section. Taking into account the direction of flow and the shape of the transport pipeline, the main parameters of hydrotransportation were determined both in the ascending and descending sections of the pipeline.

In this stand, cylindrical capsules with the following characteristics were used as the transported material:

$$ds/D = 0.68 - 0.87, \quad ls/D = 2.4 - 7.2, \quad \rho_s/\rho_w = 1 - 3.4.$$

Here ds, ls and ρ_s are the diameter, length, and density of the capsule, respectively, and ρ_w is the density of the carrier liquid (water).

It should be noted that the capsules indicated above and used for all the described stands closely enough simulated the characteristics of natural marine nodules, provided they were transported inside the considered capsules.

3. RELATIVE VELOCITY

The main task of this stage of our research was to conduct test studies of specific hydraulic resistances I and average velocity of capsules V_S for var-

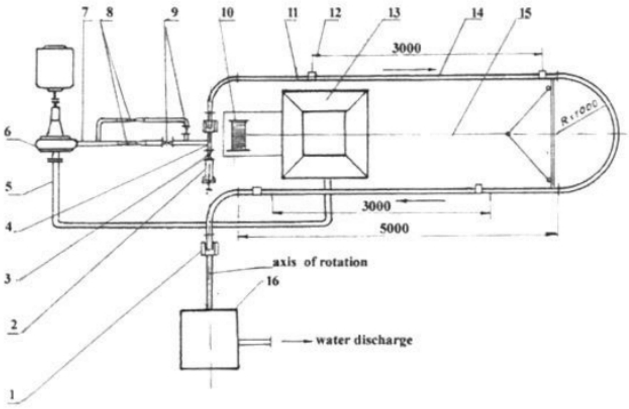


Fig. 3. Diagram of the U-shaped pipeline stand

ious flow regimes and geometric characteristics of solid bodies (capsules) in the mixture. It is these parameters that are decisive in the development of hydrodynamic methods for calculating such pipeline systems. At the same time, from a scientific and practical point of view, the question of the ratio of the average velocities of the capsules and liquid phases in such flows is of fundamental importance. This characteristic is one of the most important for determining the operability and ensuring the reliability of the pipelines of the class under consideration.

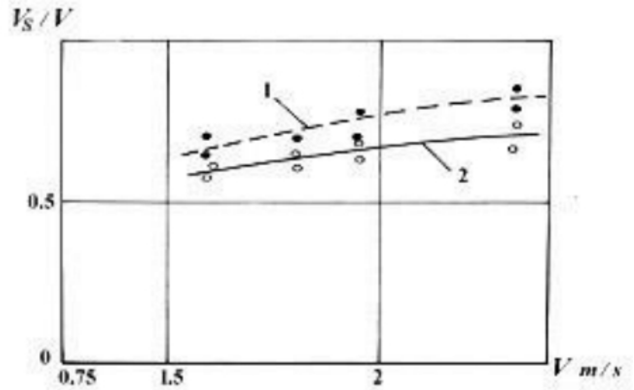
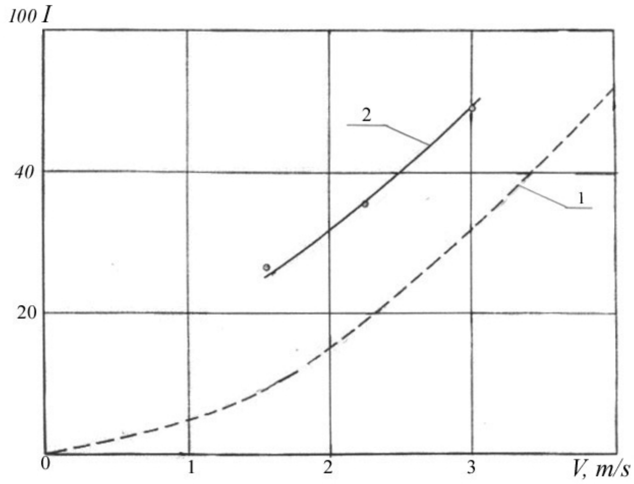


Fig. 4. Dependence of the relative velocity of flow of solid lumpy materials V_S/V on the average flow velocity V

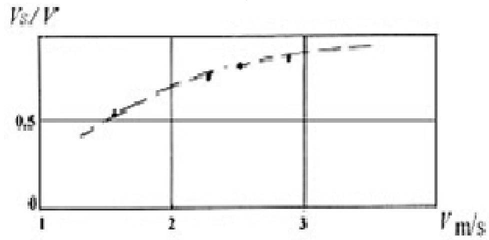
As an example, the characteristic dependences of the values V and V_S for the pipeline (Fig. 2) with inner diameter of 20 mm are shown in Fig. 4. As the analysis of these results demonstrates, especially with regard to data relating to the relative velocity of movement, the nature of the dependence of this value correlates quite well with our earlier data [1–3] on the vertical hydrotransport of large solid particles and cylindrical capsules with sufficiently large relative diameter.

$D = 20\,\text{mm}; \quad d_S/D = 0.6; \quad \rho_S = 2000\,\text{kg/m}^3.1{-}S = 2.25\%; \quad 2{-}S = 8.3\%.$

Here S is the volume concentration of the solid phase in the flow.



a)



b)

Fig. 5. Dependence of the specific hydraulic resistance I – (a), and relative velocity of capsules V_S/V on the average flow velocity V – (b).
$D = 29$ mm; $d_s/D = 0.77$; $l_s/D = 7.2$; $\rho_s/\rho_w = 3.4$;
1 – specific hydraulic resistance for clear water;
2 – specific hydraulic resistance for capsules flow

In Fig. 5, as an example, the characteristic dependences of specific hydraulic resistances and the relative velocity of capsule movement in the vertical pipeline with $D = 29$ mm are shown (stand Fig. 3).

4. SPECIFIC HYDRAULIC RESISTANCES

Our analysis also showed that the calculation of specific hydraulic resistances, as well as the relative capsules velocity for various diameters and densities in vertical pipes of relatively small diameter, can be carried out according to the recommendations presented in [2].

In particular, we processed the specific hydraulic resistances of the capsule flows not only in the vertical, but also in the inclined (ascending and descending) sections of the pipeline. The corresponding processing of the experimental material showed that in this case, for practical calculations, hydraulic resistances can be determined reliably enough by the formula:

$$I = I_w \pm \left(\left(\rho_s - \rho_w \right) / \rho_w \right) S \sin(\alpha), \tag{1}$$

where the signs + and − are taken respectively for the ascending and descending sections of the pipeline. In this formula I_w, ρ_s, S, ρ_w are, respectively, the specific hydraulic resistances when moving in the pipeline of pure water, the density of the capsules, the volumetric concentration of the capsules in the measuring section, the density of the carrier liquid, and is the angle of inclination of the pipeline.

The result obtained is clearly illustrated in Fig. 6, which presents our initial experimental data, recalculated minus the second term on the right-hand side of (1), taken with its own sign.

In the future, it will be of great interest to generalize the obtained experimental data with the data that will be obtained on a series of stands with a larger diameter (diameters that will be close to the pipelines actually used in practice – $D \geq 150$ mm). The results of such generalization will make it possible to develop practical recommendations for the calculation and design of industrial systems for vertical hydraulic lifting of nodules in capsules from the bottom of the seas and ocean.

5. CONCLUSIONS

In conclusion, we note that the preliminary results presented here can serve as a basis for the development of scientifically grounded methods for calculat-

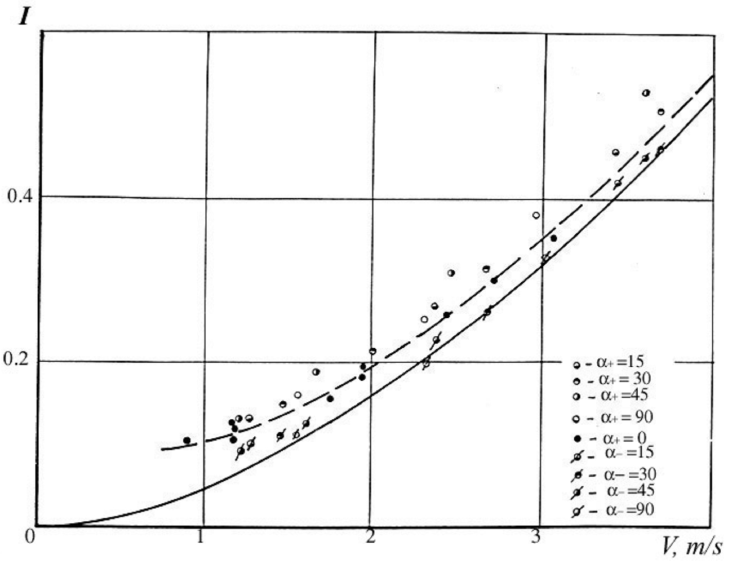


Fig. 6. Dependence of specific hydraulic resistance I for capsules flow on the average velocity V for horizontal, inclined and vertical sections of the pipeline

ing vertical hydrotransport systems both for traditional suspensions containing large lumpy materials and capsules that transport various kinds of bottom nodules. The development of such calculation methods will be the subject of our further research.

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