

III. Новітні технології та устаткування до енергобезпечних робіт

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DEVELOPMENT OF NEW ENERGY-SAVING TECHNOLOGIES IN THE SYSTEMS OF HYDRAULIC PIPELINE TRANSPORT

У роботі розглянуті гідродинамічні аспекти щодо нового виду трубопровідного транспорту - капсульного гідравлічного трубопровідного транспорту (КГТТ). Показано, що КГТТ може виявитися значно ефективніше (з точки зору енерговитрат) в порівнянні з відомими традиційними видами трубопровідного транспорту твердих дисперсних матеріалів і високов'язких рідких продуктів.

Ключові слова: капсульний гідравлічний трубопровідний транспорт, енерговитрати.

В работе рассмотрены гидродинамические аспекты относительно нового вида трубопроводного транспорта – капсульного гидравлического трубопроводного транспорта (КГТТ). Показано, что КГТТ может оказаться значительно эффективней (с точки зрения энергозатрат) по сравнению с известными традиционными видами трубопроводного транспорта твердых дисперсных материалов и высоковязких жидких продуктов.

Ключевые слова: капсульный гидравлический трубопроводный транспорт, энергозатраты.

Hydrodynamic aspects of a new type of pipeline transport - capsules hydraulic pipeline transport (CHPT) are considered in this paper. It has been shown that CHPT can be much more effective (from the point of view of energy costs) in comparison with the traditional conventional types of pipeline transport of solid dispersed materials and highly viscous liquid products.

Keywords: capsules hydraulic pipeline transport, energy consumption.

In connection with increasing the volume of transportation of various disperse and viscous liquid products, the problem of finding and implementation the new and effective methods of transportation these materials has arisen before the national economy.

In this regard, one of the perspective methods of pipeline transportation is capsules hydraulic pipeline transport (CHPT), in which the transported material is loaded into capsules (containers) and moves through pipes using a liquid (water) flow. Particularly relevant is the introduction of this type of transport in those regions where it's possible to organize simultaneous transportation of water and various products in capsules in one common pipeline. As a capsule, reusable rigid shell as well as disposable, strong, elastic containers (bags) can be used. As a rule, the most appropriate is the using the capsules in a form reminiscent of the shape of the cylinder. Schematic diagram of the linear part of the capsules hydraulic pipeline transport is shown in Fig.1

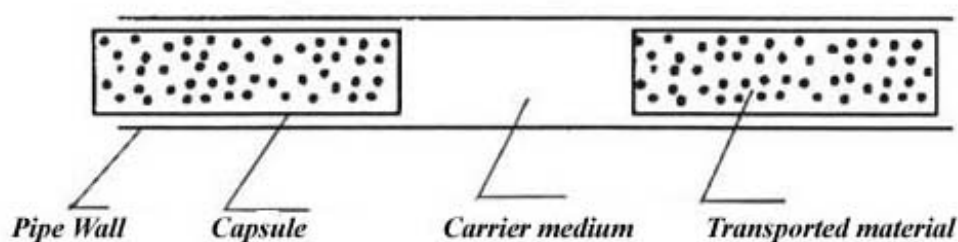


Fig.1 Schematic diagram of capsules pipeline hydrotransport

At the present time the research carried out by domestic and foreign authors have shown that CHPT can be, in principle, successfully applied in numerous areas of the national economy for transportation of different agricultural products, as well as in the coal, petrochemical and mining industries [1-4]. However, the absence the universally recognized, evidence-based method of calculation the basic parameters of hydraulic capsules transportation does not allow so far to estimate the reliability and effectiveness of CHPT, which largely hinders its wide implementation.

In this paper a brief description concerning results of theoretical and experimental studies performed in recent years in IGM NAS of Ukraine in the area of CHPT are presented. The purpose of these research was study such parameters of CHPT as the average velocity at which the movement of the capsules begins (starting velocity), as well as the hydraulic resistance and the relative velocities of the capsules on the horizontal, inclined and bend sections of the pipeline. The possibility to evaluate the above parameters makes it possible to provide the stable operation of the entire transport system, determine its throughput, select the necessary pumping and other equipment.

It should be noted that the formulated problem of calculation the basic parameters of CHPT is part of a rather complex and not enough studied problem of hydrodynamics which maybe associated with the motion of bodies in a fluid under the constrained conditions. At present, when solving such problems its advisable to use a complex approach, which includes both the development of a general mathematical model for the object of investigation (in our case, the capsules flow) and large-scale experimental studies.

In the development of the mathematical model of capsule flow, the joint movement of liquid and capsules through the pipeline was considered from the point of view of discrete two-phase flows [1-2], which allowed to apply for such kind of systems the modern methods of mechanics of multiphase medium. In this case the probabilistic averaging and the theory of

generalized functions in the presentation of dynamical macroscopic equations were used. So it was possible to correctly derive the equations of continuity and the equation of motion separately for capsules and the surrounding liquid.

The obtained equations made it possible to identify the numerous characteristic features of the joint motion of liquid and capsules through a pipeline and within the frame of a one-dimensional problem to obtain the structure of expressions for calculation the basic parameters of hydrotransportation of capsules of various buoyancy. Because the system of hydrodynamic equations was not closed, in the resulting calculated expressions there were some number of unknown parameters. In our approach these parameters were determined on the base of experimental data.

Experimental studies of the basic parameters of CHPT for capsules with different buoyancy on straight horizontal pipelines were conducted on three connected pipe installations (inner diameters 25, 58 and 125 mm) and two open-ended ones (inner diameters 12 and 37 mm).

The studies of hydrotransport the different capsules on the bends two circular installations with internal diameter of 25 and 125 mm were used, including bends with angles of 30° , 60° и 90° .

The research the hydrotransport of capsules on inclined and vertical sections the laboratory installation (internal diameter of 29 mm) with an adjustable slope of the pipeline and flow-through type installation with an internal diameter of 12 mm were used. All above installations were supplied with equipments and devices enabling to simultaneously determine hydraulic resistances, average velocities of the water and capsules, and also starting velocity for heavy capsules.

The studies were conducted both with single capsules and trains of capsules of flexible and rigid walls and having spherical front end and flat rear end. While the basic characteristics of capsules were changed in a fairly wide range:

$$d_c / D = 0.56 - 0.92; \quad l_c / D = 2 - 80; \quad \rho_c / \rho_w = 1 - 8;$$

Where l_c, ρ_c, d_c - respectively capsule length, density and diameter, ρ_w - density of the carrier medium, and D - pipeline diameter.

The significant amount of experimental research performed regarding the basic dynamic parameters of hydrotransportation has greatly expanded and generalized the well known experimental data, which are presented in the literature.

Fig. 2a shows, as an example, the typical dependences for hydraulic pressure gradient I and the relative velocity V_c / V_{AV} for heavy capsules $\rho_c > \rho_w$ on the average flow velocity V_{AV} . For such regime of transportation, the motion of capsules begins at a certain velocity (starting velocity V_{ST}).

For the following velocity mode $V_{AV} > V_{ST}$, the hydraulic resistance of the capsule flow I (energy consumption) is generally higher than the hydraulic resistance for pure water I_w .

As to relative velocity of the capsules V_C / V_{AV} (Fig. 2a), the value of V_C / V_{AV} increases with increasing V_{AV} , and then asymptotically approaches to certain constant value. This value in our experiment (similar to the experiments of another authors) are changed from 1.05 to 1.2, while the value of the relative velocity grows with the increasing the diameter of capsule and decreases with increasing the length and density of capsule.

Fundamentally new results [1-3] were obtained during the study the motion of capsules in bend, on inclined and vertical sections of the pipeline, and also when the capsules have a density close to the density of the carrier liquid (capsules of neutral buoyancy).

In particular, as to experimental results obtained with all six experimental installations, pressure gradient (hydraulic resistances I) in the liquid flow with flexible and rigid capsules of neutral buoyancy turned out to be almost identical to the ones in the similar flow of homogeneous liquid. This is visually illustrated by the Fig.2b (curve 1).

In the same time, the relative velocity of capsules V_C / V_{AV} (Fig. 2b, curve 2) remains almost constant over a wide range of V_{AV} and depends only on capsules geometry: it increases when relative length of the capsule grows and decreases when its relative diameter increases.

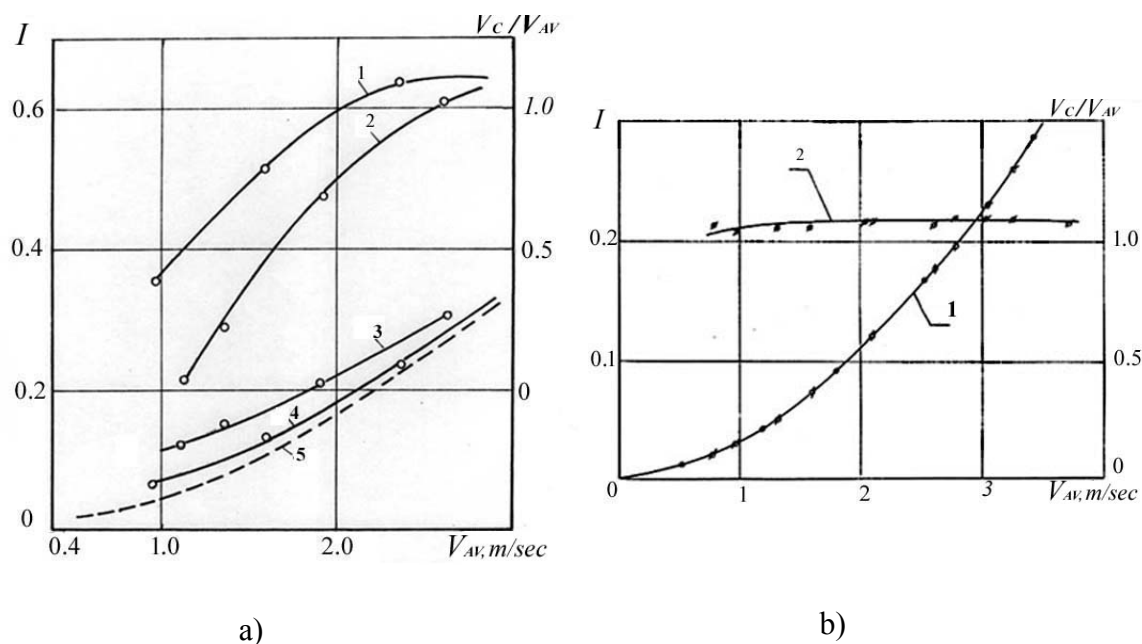


Fig.2 Dependence of pressure gradient (I) and relative velocity of capsules (V_C / V_{AV}) on the average flow velocity V_{AV} for heavy capsules (a) and capsules of neutral buoyancy (b)

a) – $D=25\text{ mm}$; $d_C / D=0.64$; $l_C / D=4$; 1,4 – $\rho_C / \rho_W = 4$; 2,3 – $\rho_C / \rho_W = 8$;

3,4,5 – $I = f(V_{AV})$; 1,2 – $V_C / V_{AV} = f(V_{AV})$; 5 – $I = f(V_{AV})$ for water

b) – $D=37.2\text{ mm}$; $d_C / D=0.95$; $l_C / D=19$; 1 – $I = f(V_{AV})$; 2 – $V_C / V_{AV} = f(V_{AV})$;

• – water; ϕ – capsules

The last obtained results have the fundamental importance, since the question of the nature of the motion of neutral buoyancy capsules is still debatable. This is due to the fact that such kind of flows are fundamental for testing various methods of mathematical modeling for the motion of bodies in a fluid under the constrained conditions. In practical terms, the latter result allows us to make an important conclusion about the special efficiency of using CHPT for transportation of various materials with a density close to the density of the carrier fluid. This may be applied, first of all, to the transportation of oil and oil products, and also to those bulk solid materials, the volume density of which in capsules is close to the density of the carrier medium.

Special attention was also devoted to the study of the kinematic structure of capsules flows, since by now these questions were practically not studied. To study the turbulent characteristics of hydraulic pipeline capsules flows, the electrodiffusion measurement method was first used in our paper [1]. Thus, the whole set of experimental data obtained in our research concerning the dynamics and kinematics of capsule flows [1-3] was a reliable base for the development of generalized method of hydraulic calculation for CHPT systems.

In this case, the mathematical model and experimental data were used as a base for development an engineering method of calculation the main parameters of CHPT when the capsules move on straight horizontal sections of the pipeline [1-3]. In addition, recommendations for calculating the parameters of hydrotransportation of capsules in bends, on inclined and vertical sections of the pipeline were also developed.

In general, the reliability of the calculated dependencies proposed in the paper was verified on the most of experimental material known in the literature, including foreign authors. Moreover, the operation of all assembly units and equipment for capsule pipeline systems were successfully implemented and tested in IGM NAS of Ukraine on a semi-industrial experimental stand ($D=125\text{ mm}$).

The recommendations developed in such a way can be served as a base for design industrial and main capsule pipeline hydraulic systems. In addition, this methodic also makes it possible to estimate the effectiveness of CHPT and advisability of its using in various areas of the national economy.

As known, energy consumption (energy costs) is one of the main indicators of the effectiveness of considered kind of transport. Therefore, a great interest is to compare the energy costs of CHPT with other types of pipeline transport. For the case of transportation of bulk solid materials, CHPT its reasonable to compare with traditional hydrotransport of slurry, and for viscous liquid products - with the usual pipeline transport of these materials. Some results of this kind of comparison are shown in Fig 3.

Our calculations concerning the transport of solid dispersed products have defined that, other things being equal, the transportation of such materials in capsules is generally more efficient than using the traditional pipeline hydrotransport of these materials in the form of slurry. At that, for some bulk solid materials this advantage, as seen in Fig.3a, can be more than 2-3 times. For definiteness, on this figure as the material to be transported the coarse-grained coal was chosen. For this case the diameter of the pipeline $D=307\text{ mm}$, the average volume coal concentration $S=0.2$, and the average density of the solid material -

$\rho_s = 1600 \text{ kg/m}^3$. Numerous calculations have shown that saving in energy costs will be the more than higher the average size and lower the density of the transported material.

As for the comparison in the transportation of viscous liquid products, the decrease in energy consumption for CHPT relative to traditional pipeline transport will be significant (up to 2-4 times), than higher the viscosity of transportation materials.

Figure 3b, as an example, shows the energy costs for transportation of oil/ petroleum from the famous “Russkoye field” directly through the pipeline $D=500 \text{ mm}$ at $t^0 = 10^\circ \text{C}$ and with using of CHPT in a pipeline of the same diameter ($d_c/D=0.9$). In comparison it was assumed, that in both cases the total volume flow rate of oil $Q(\text{m}^3/\text{sec})$ remains constant, and the CHPT of oil is realized in polyethylene capsules (bags) with distances between capsules equal to their length.

In conclusion, we have to note that our preliminary results obtained in this paper have established sufficient effectiveness of the considered alternative capsules hydrotransport. In particular, from the results given in the work, it follows that CHPT can be significantly more efficient (from the point of view of energy costs) in comparison with the well known traditional types of pipeline transport. At the present time in Ukraine and abroad the complex research related to evaluation the more perspective areas of using CHPT are discussed among scientists and constructors.

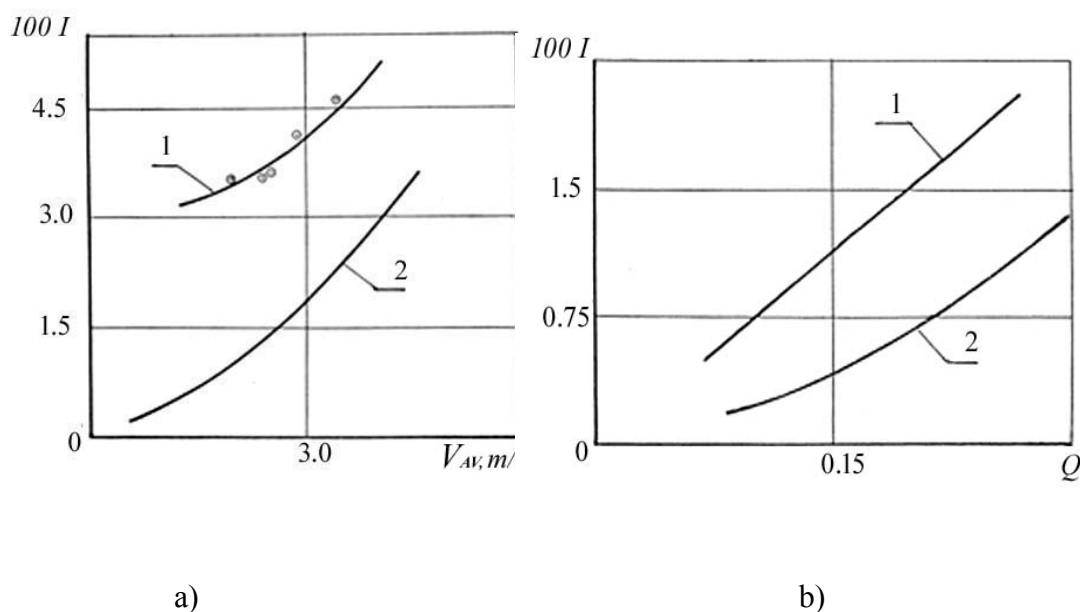


Fig. 3 Comparison of energy costs for various types of pipeline transport for carriage of bulk solid materials and viscous liquid products

a) Energy costs for hydrotransportation of coal class 0-70 mm;

$$D=307 \text{ mm}; S=0.2; \rho=1600 \text{ kg/m}^3$$

1- slurry transportation; 2 - CHPT

b) Energy costs for transportation of oil

from the “Russkoye field”, $\rho=960 \text{ kg/m}^3$

1- traditional pipeline transport of oil; 2 – CHPT

REFERENCES

1. V.Berman, S.Kril and P.Vlasak Hydrodynamic and kinematic parameters of hydraulic capsule flow, Hydrotransport 15, Banff, Canada, 2002, p.233-245.
2. A.Oleynik, V. Berman S. Kril S., V. Karasik V., Ocheretko , Hydraulic pipeline transport of containers, Naukova Dumka, Kiev, 1983, -124 p.
3. V. Berman and P. Vlasak, Some specialties of neutral buoyancy hydraulic Capsules flow in horizontal pipe, 8th International Conference for Conveying and Handling of Particulate Solids, 2015, Tel Aviv, 9 pages
4. H.Liu, S.Mohandas Experimental study of capsules lift-off in a 190 mm pipe, J. Pipelines, 6, 1987, p.253-262.
5. Kril S, Suspension Conveying Pressure Flows, Naukova Dumka Publishing House, Kiev, 1990, - 159 p