SOME ASPECTS OF USING ELECTRO – DIFFUSION METHOD FOR DIAGNOSTICS OF KINEMATIC STRUCTURE OF SOLID – LIQUID FLOW IN PIPELINES

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Some aspects concerning using of electro-diffusion method for diagnostics of the kinematic structure for motion of traditional slurry and also the motion of massive solid materials in pipeline are considered. The results of comparison of the obtained experimental data with various calculation methods are presented. It was found that, despite its relative simplicity, the electro-diffusion method can be successfully used for determining the values of tangential stresses and distribution of averaged velocities in the considered by us flows. It was also derived that the data as to the kinematic characteristics should be taken into account in the development the hydraulic methods of calculating the main parameters for solid-liquid flows in pipeline.

KEY WORDS: electro-diffusion method, hydraulic pipeline transport, kinematics structure, slurry flow, capsules flow.

1. INTRODUCTION

At present, for study of the whole range of issues both fundamental and applied fluid mechanics, the modern methods of diagnostics of such flows are required. In particular, it relates to the problem of the motion of traditional slurry in pipeline, and also to the motion of massive solid bodies in a liquid at cramped conditions. The paper considers the problems of motion of traditional slurry and axially symmetric and asymmetric motion of bodies of cylindrical shape in the pipes. In practice, the last problem is directly connected with using of hydraulic capsule pipeline for transportation of various bulk and viscous-liquid materials (Liu, 1981; Mizsushina, 1971, Ginevsky et al., 1975, Berman and Kril, 1981, Berman et al., 1995, 2002, 2018; Berman and Vlasak, 2015). Despite the existing diagnostic techniques of suspension kinematics, the search for alternative and simple diagnostic methods for such flows presents both scientific and practical interest. As concerns to the motion of massive solid materials in pipeline, then there are practically no experimental data on kinematics in general.

The purpose of this work is the development of a fundamentally new method for diagnosing the structure of turbulent flows in pipes of mixtures of liquid and solid particles,

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including large solids. The relevance of the work is determined by the need to create modern methods and measurement techniques, allowing the most complete study of averaged and pulsation characteristics for such flows. Investigation of structure of pressure of suspension media is fundamental in nature and is closely related to the problem of turbulence for flows of disperse systems. The results of these studies will not only enable us to better study the turbulent characteristics of the flows under consideration, but also significantly improve the existing physical models of the flow of slurry in the pipes and develop, on their basis, more universal and reliable methods for calculating the parameters of hydrotransport of solid materials.

At present, for experimental research of the structure of velocities and tangential stresses of turbulent suspended flows, mainly high-speed filming and various types of anemometers are used. However, these measurement methods have certain disadvantages – they are very labor-intensive and require a significant investment of time and material resources. In this connection, the more simple and effective method for the experimental study of turbulent characteristics, based on the electro-diffusion measurement method (EDM) (Pokryvaylo et al., 1988, Mizsushina, 1971), is of great interest.

The essence of the method is that a certain electrolyte solution is used as a carrier media, and special electrodes are used as a sensor. The value of the measured characteristic is determined by the current strength between the electrodes placed in the flow. For a given composition of the electrolyte solution and electrical voltage at the electrodes, the current between the electrodes depends on the speed of flow around the working element. At present, this method of measurement has proved to be quite successful in studying the flows of water-air and homogeneous mixtures.

For research in the Institute of Hydromechanics, National Academy of Sciences of Ukraine a universal stand with internal diameter D = 12 mm was created (Berman et al., 2002). It allows to study the kinematic structure of both - slurry and flows containing single large bodies (capsules) and capsule trains. The experimental stand was also supplied with both equipments for EDM and with instruments and devices allowing measuring simultaneously the kinematic and integral characteristics. This, in its turn, made it possible to provide reliable calibration of all devices using EDM. Schematic diagram of the experimental stand and instrumentation is shown in Figure 1 and Figure 2.

2. ELECTRO - DIFFUSION METHOD OF DIAGNOSTIC

In our case, a very thin platinum wire was used. Wedge-shaped form and small dimension of velocity sensor holder practically eliminate a possibility of vortex field originated around the sensor effect on the sensing element itself, created by the incidence cross-section of the very thin platinum wire. As a holder of the velocity sensors a medical needle of small size (diameter of 1.2 mm) was used. A high quality of the platinum wire isolation is very important to assure maximum stable condition of the main electrode. For this reason, double protection of the wire, i.e. glass-capillary and epoxy embedding, was used. Also, the minimum roughness of the velocity sensor front part is very important, thus it is necessary to work it carefully, without any burrs.

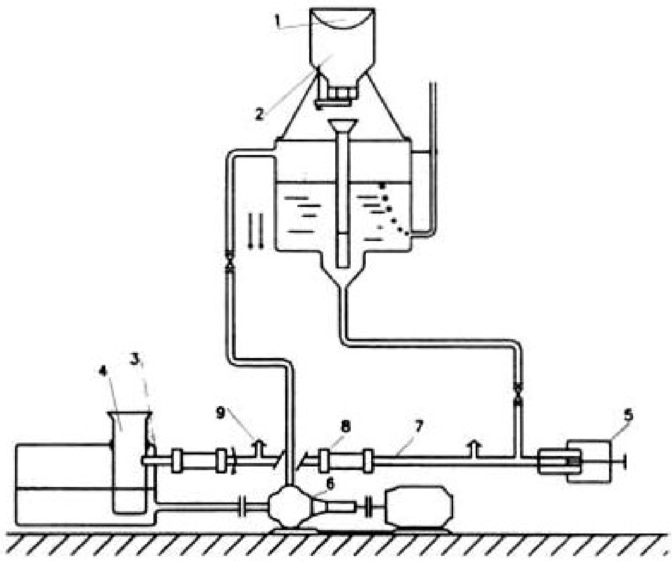


Figure 1. Layout of universal experimental stand. (1- solid phase feeder, 2- pressure tank, 3- filter, 4- receiving tank, 5- massive body/capsule inlet, 6- pump, 7- pipe, 8- transparent pipe section, 9- pressure sampling fittings)

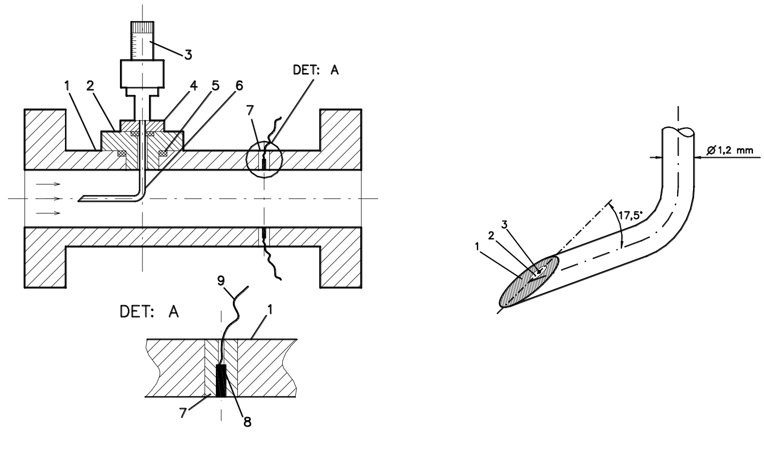


Figure 2. Diagram of the measuring enclosure with the velocity and the tangential stress sensors (1 – enclosure, 2 – plug, 3 – micrometer screw, 4 – packing, 5 – sealing ring, 6 – velocity sensor holder, 7 – pressure sensor holder, 8 – pressure sensor, 9 – pressure sensor outlet)

According Mizsushina (1971) and Pokryvaylo et al. (1988) the electrical current output I over τ relationship can be approximated by 1/3 law, and similarly for I over V relationship I over V a 1/2 law can be used, $I = A \,.\, \tau^3$ and $I = B \,.\, V^2$.

In Figure 3, the calculated (line) and experimental EDM data (points) are compared. It was proved that the measured calibration curves coincide well with the characteristics predicted by the theory of current diffusion.

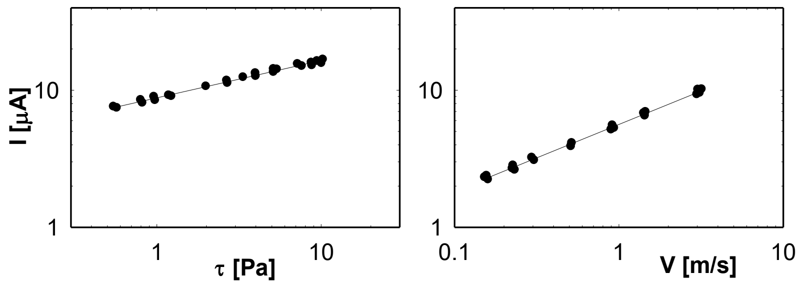


Figure 3. Comparison of calculated and experimental values – dependence of electrical output I on tangential stress τ and velocity V, respectively

The next step of our work was a verification of using EDM not only for traditional single-phase flows, but also for multiphase flows of different structures. In particular, we carried out a whole complex research for suspensions (mixture of liquid and solid particles) flows in pipes.

3. EXPERIMENTAL RESULTS - COMPARISON OF CALCULATED AND EXPERIMENTAL DATA

Thus, in the case of slurry flows, a relatively large amount of experiments for sand with a medium size d_s = 0.31 mm was performed, while the average flow velocity and volume concentration were varied in a quite wide range. Figure 4 shows the characteristic dependence of tangential stresses in the liquid phase as a function of the angle characterizing the different points on the wall of the pipe (Hanratty, Campbell 1983). Here the angle, α = 0°, corresponds to the lower, and α = 180° - to the upper point of the pipe wall. As can be seen from this figure, the dependence obtained is in a satisfactory agreement with well-known theoretical solutions (Kril, 1990, Bournaski et al., 2017).

After our experiments concerning the use of EDM for slurry, now we turn directly to the study of the kinematic for transportation of massive bodies moving in a fluid flow in pipes. In what follows, these flows will be called capsules flows, especially since in our studies we used cylindrical capsules as large massive bodies. At the same time, the relative diameter, length, and density of the capsules were changed in a relative wide range. Initially, in this part of our research as for using of EDM, the main attention was devoted to the study of the distribution of tangential stresses, τ = f(α), on the pipeline wall for flow in annular gap around the capsule. Here also the angle, α = 0°, corresponds to the lower, and α = 180° - to the upper point of the pipe wall.

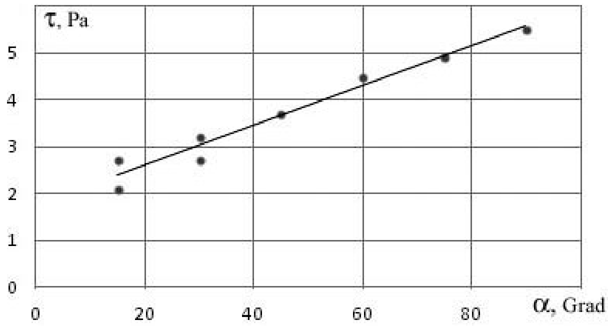


Figure 4. Dependence of tangential stresses τ on angle α. Sand slurry; $V = 1$ m/s, $S = 0.14$

Figure 5 shows, as an example, the dependence of tangential stresses on the angle for liquid flow around an axially symmetrically located in the pipe the fixed capsule. The same figure shows the calculated dependence known in the literature (Ginevsky et al., 1975; Berman et al., 2002) for calculation when liquid moves in the annular gap. As one can see, there is a quite satisfactory correspondence between experimental and calculated data.

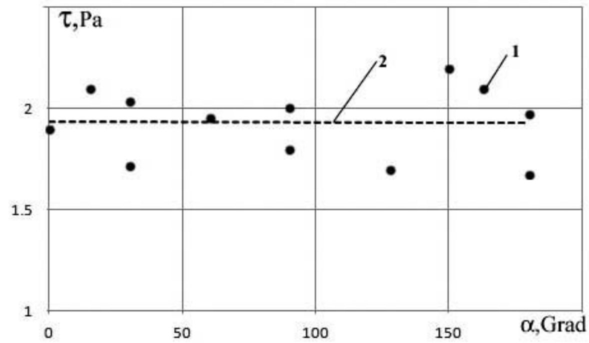


Figure 5. Dependence of tangential stresses τ on the pipe wall on angle α for axially symmetric flow in the annular gap around a fixed capsule 1- experiment, 2 - calculation according to Ginevsky et al. (1975) and Berman et al. (2002)

Similar experiments were carried out for axially symmetrically moving single capsules. Earlier it was shown that a relatively stable axially symmetric movement of capsules can be realized if the density of these capsules is equal to the density of their carrier fluid (capsules of neutral buoyancy). Here it should be noted that the study of such flow regimes still initiated some interest among a number of researchers (Ginevsky et al., 1975, Berman and Kril, 1981; Berman et al., 1995, 2002; Berman and Vlasak, 2015). This is primarily due to the fact that such a motion of bodies in a fluid at cramped conditions is fundamental for testing various methods for modeling such kind of flows. The characteristic dependences of the tangential stresses on the pipe wall on the angle for the moving capsules of neutral buoyancy (at different average velocities V are shown in Figure 6.

It is interesting to compare the obtained experimental data with the available methods for calculating the kinematic structure of such flows. At present, there are a number of hypotheses concerning the distribution of tangential stresses in the annular gap (the space between the surface of the capsule and the wall of the pipe). Figure 7 shows such a comparison of the experimental and calculated according to the method proposed by the authors regarding the values of tangential stresses on the pipe wall at motion of single capsules of neutral buoyancy.

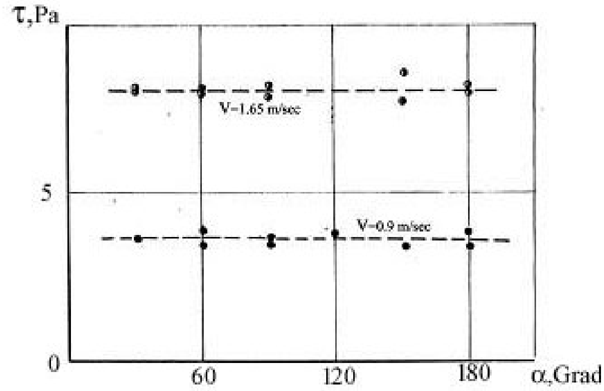


Figure 6. Dependence of tangential stresses τ on the pipe wall on angle α for axially symmetric flow in the annular gap around a moving capsule.

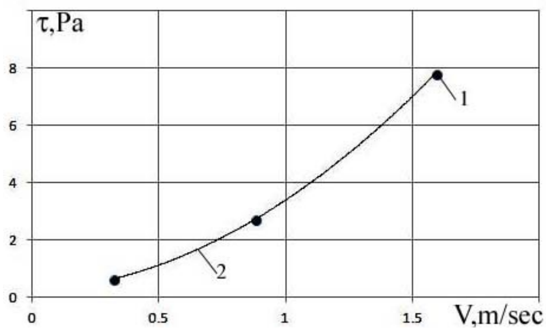


Figure 7. Dependence of tangential stresses τ on the pipe wall on average velocity V for flow of axially symmetric capsules (neutral buoyancy); 1 - experiment; 2 - calculation (Berman et al. 2002)

As can be seen from Figure 7, there is a quite good correspondence between experimental and calculated data. Now we consider the comparison of the experimental data as to kinematic of the capsules flows (experimental data based on the EDM) with those experimental data which have been obtained on the basis of dynamic integral characteristics of these flows. As an example, we will first consider the comparison of experimental data relative to tangential stresses τ. The results of this comparison, for a number of different single capsules, are presented in Figure 8.

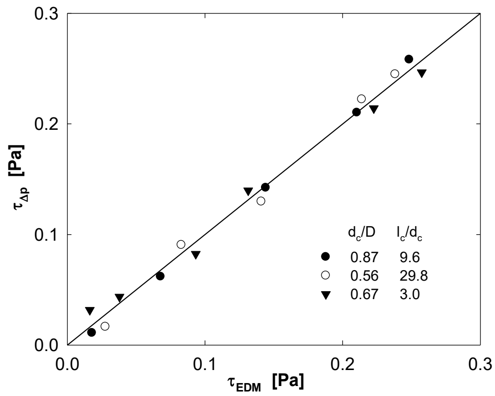


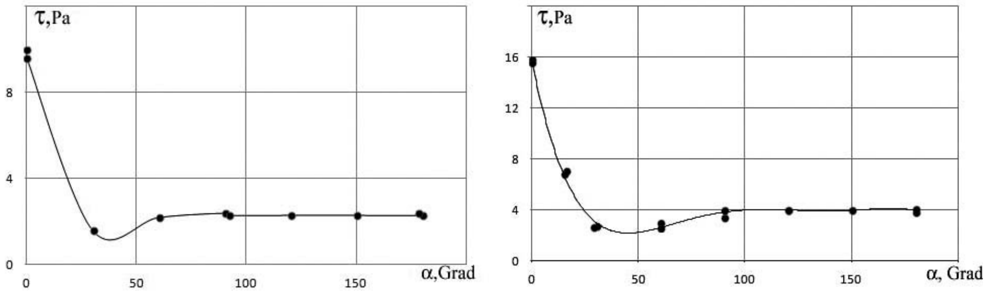
Figure 8. Comparison of shear stress value from pressure difference $\tau_{\Delta P}$ and from EDM measurement τ_{EDM}. Capsules of neutral buoyancy.

Figure 8 shows good correspondence of tangential stress value $\tau_{\Delta P}$ obtained by direct measurement of pressure gradient/difference and on the basis of EDM τ_{EDM},, if neutral buoyancy capsule is conveyed in straight horizontal pipe. Coincidence of the data for neutral buoyancy capsules gives also the reason for using of EDM for measurement of kinematic parameters of capsules with density different from that of the carrier liquid. EDM made possible to obtain and to generalize some very important parameters of capsule pipeline transport, in particular, the lift force, the specific hydraulic resistance, the pressure loss at the ends of the capsule and other defining characteristics. Here d_c/D and l_c/D are the relative diameter and the relative length of the capsule, respectively.

4. CONCLUSIONS

In conclusion, we note that a particular interest represent the data, which characterize the change, $\tau = f(\alpha)$, for motion of the capsules with density greater than that of the carrier liquid in pipe (heavy capsules). As far as we know, such data are not available in the literature at all. For this case, the character of the dependences, $\tau = f(\alpha)$, obtained in the work, for various average flow velocities V, is shown in Figure 9. The last results were obtained by us for the first time, and on the basis of these data it is possible to solve a number of fundamental problems, for example, the calculation of the lifting force during the movement of heavy capsules, calculation of head losses at the ends of the capsule, or calculation of fluid flow in the annular gap, etc. It is quite clear that without using of EDM, it is not possible to obtain these results.

Even these preliminary results, apart from purely scientific ones, can also have a certain methodological significance, since it's possible to judge with certainty the reliability of using of EDM for diagnosing a kinematic structure of the flows, which have been considered in this work. Currently, the experimental material obtained in this work is used to refine the methods developed by the authors for calculation the basic parameters of both hydraulic capsule pipeline transport and hydrotransport of different slurry flows.



b)

Figure 9. Dependence of tangential stresses τ on the pipe wall on angle α at motion of a heavy single capsules; a) V = 0.6 m/s, b) V = 1.0 m/s

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