Experimental research of microturbulence and transportability on sliding surfaces

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Abstract. The possibility of increasing the pipeline transport capacity was analyzed with the points of the development of the pipeline inner surface roughness. An effective consequences of the pipeline inner surface roughness modification were observed. The positive effects and essential needs of the research progress in this area were noticed. The method of carrying out experiments for investigation of the flow transport capacity development in the open chute with the different roughness structure were introduced. Changing the geometric shape of the internal surface of the pipe by placing artificial protrusions (obstacles) creates the flow vortex formation (micro-turbulence).

A testing bench for investigation of turbulence and carrying capacity of flow of fluid by optical means in the open pipe with the different location of their internal protrusions were used. The bench includes a working surface in the form of open chute; a water container.

The flow characteristics, hydraulic parameters (design water stream, speed, filling, slope, etc.), were accompanied on the bench by filming and continuous -shadow multi-frame photography using a light effect to reflect the vortex configurations and backwater in the frontal parts of obstacles. The transport capacity was checked by ability of transportation for sand mineral impurities groups. As an obstacle of a fluid flow, various configurations of obstacles created a microturbulence. The obstacles are made in the form of barriers of short objects of rectangular cross-section, located at different angles to each other, uniformly distributed along the length of the tray.

Based on the conducted researches, the optimal type and parameters of obstacles for an improvement of the transport capacity are established.

1. Introduction

To ensure efficient transportation for gravity wastewater pipelines, which contain large amounts of suspended solids, it is necessary to create several conditions affecting the flow rate to find the appropriate slope of the pipe trays and their contents [1]. Some influence is attributed to the state of the internal surface of pipes (especially of 100-200 mm small diameters), which whenever possible should have a minimum value of the hydraulic friction contributing to an efficient water flow with simultaneous displacement of suspended particles [2]. Provision shall be made of prediction of critical deposition rate and, therefore, the impact of removal of solid inclusions in relation to the average rate, the pressure gradient in the flow direction [3, 4]. It is also important to evaluate the composition of the suspended solids, their concentration, particle size and degree of the mixture homogeneity [5, 6]. The
inner pipe surface may be considered as an ideal one, if it is performed in such a manner, that the suspended particles shall be transferred even at the rates below the critical ones (less than 0.7 m/s) [7].

However, if the flow rate remains below a critical (self-cleaning) one for a long period of time, the impurities are not held in suspension and precipitate, forming a dense deposit. However, even a smooth inner surface of the pipes will not contribute to the movement of precipitated particles and the caked dirt of mineral and organic nature, as the turbulent flow mode becomes a laminar one [8].

Some deposits, mainly the upper layers with a relatively great content in the pipeline, can be removed by the flow in hours of the maximum water consumption in the city and the caked sediments can stay in the chute portion of the pipe, that will require the periodic cleaning of the pipeline by various methods. This situation may lead to inefficient operation of the pipeline system: degradation of its performance or additional costs to overcome the friction forces in the result of narrowing the pipeline living section.

Researchers put forward the idea of creating such a structure of the pipe inner surface, where the quantity of deposited sediments would be minimal regardless of rates and the content in the pipeline [9]. In addition, the inner surface of the piping shall have the mechanical strength and a low degree of abrasion [10, 11].

The examples of living nature, such as the blood vessels of the wings of insects and the system of transport of water and mineral salt nutrient solutions from the roots to the leaves in the tissues of higher plants, i.e. in the so-called xilema, have been an impetus for purposeful work to ensure the efficient transportation of liquid and solid substances through pipelines [12, 13]. The vessels having a multilayer spiral growth on the inner walls are formed in the xilemas of the plants. These sorts of seals contribute to formation of a local turbulence (swirl) flows, which allow the transfer of fluids to the destination point without stagnation zones. A certain effect in increasing the carrying capacity can be provided by hydrophobic surfaces, which have a specific relief in the form of a group of “spike”-type ruffles [14, 15].

Wide opportunities of modern technologies of production of pipes and internal protective coatings of composite materials with nearly any surface structure contribute to solution of the put problems by implementing trenchless methods of the engineering systems [16, 17].

The present studies are aimed at testing the above assumptions about the possible intensification of the process of sediment transport at low water flow rates using different corrugated structure of the inner surface of the tray, which leads to the use of polymeric sleeves with a wide variety structure of ruffles and their geometric dimensions [18].

At the first stage of research works the experiments were carried out to study the hydrophobia of internal protective coatings of pipes, which can also serve as a way of increasing their transferring capacity [19].

The second phase of research and its results were aimed at identifying the optimal patterned structures as to ensure microturbulence due to the geometric shape and location of the protrusions (obstacles) and the increase of the flow transferring ability [20].

The goal of the research was to identify the optimal possible corrugation structures on the inner surfaces of the pipes, which enable the greatest effect of transporting impurities at low rates.

2. Materials and methods

Study of the efficiency of transportation of caked suspension solids by a water flow on various types of patterned surfaces, which play the role of the pipeline inner surface, has been done on a special stand (figure 1).
Figure 1. Schematic depiction of the test stand for the study of turbulence and carrying capacity of the fluid flow by optical means

1 - fixed frame; 2 - movable platform; 3 - open tray; 4 - rubber corrugated pipe; 5 - holding tank for liquid; 6 - removable mesh trap of foreign particulate inclusions; 7, 8 – cameras, respectively, of frontal and coaxial shooting; 9 - source of light radiation; 10 - mechanical jack; 11 - waterway; 12 - flexible transparent connecting pipes; 13 - movable measuring lines; 14 - plate; 15 - laser plummet; 16 - receiving measuring tank

The principle of operation of the test bench consists in the liquid flowing from a tank on the tray (130 mm diameter) with a specific surface relief and the installed slopes. At the bottom of the tray there are foreign matters (sand of various fractions of 0.1-2.5 mm). During the liquid flowing a source of light switches on and provides a contrast picture of microturbulence and movement of the matters along the tray. Based on the light-shadow effect, the relevant cameras (Sony α550 digital SLR camera, DT 1.8 / 50 SAM lens) fixe the front of the flow (the height of the layer, filling), the nature and geometrical dimensions (length, width and area of the microturbulence zones).

The parallel task provided analysis of the efficiency of the flow carrying capacity to remove the foreign particles to a mesh trap particle by smooth increase of the flow rate from 0.2 to 0.8 m/s. The water flow rate was determined via the flow transfer through a calibration curve previously constructed using the volumetric method. The slope of the open tray has been provided by a mechanical Jack and fixed by the measuring rulers according the water level in communicating tubes. A minimum slope of 0.07 for the pan of the appropriate diameter has been taken in the experiments.

During the experimental research on the bench the microturbulence phenomena have been studied on different surface relief. The picture of the roiling and movement of sand of different fractions has been studied in a wide consumption range (flow rates).

As the patterned surfaces provision has been made of several types of grouped objects, which are located at the bottom of the pan on both sides of its axis. The results of experiments on visual and hydraulic study of two following types of obstacles are given below:

- for round obstacles of 7mm diameter and 2mm height;
- cross-type bars (prisms) of rectangular section with a length of 20 mm and a height of 2 mm, mounted under the angle of 1200 to the pan axis, with circular obstacles between the bars.

The obstacles were made of polymeric materials having slight surface roughness. The camera shooting has been made of the areas with a corrugated and plane structure.
3. Results and discussions

The figure 2, as an example, shows the dynamics of changes in the removal of sandy matters with a fraction diameter of 0.1-0.3 mm at the "round obstacle" riffles.

| Picture of the flow microturbulence zones and efficiency of removal of sandy impurities | Water flow rate, m/s |
|--------------------------------------------------------------------------------------|---------------------|
| ![Image of microturbulence zones](image1)                                              | 0.1-0.15            |
| ![Image of microturbulence zones](image2)                                              | 0.25-0.3            |
| ![Image of microturbulence zones](image3)                                              | 0.4-0.5             |
| ![Image of microturbulence zones](image4)                                              | 0.6-0.7             |

**Figure 2.** Dynamics of changes in removal of impurities of 0.1-0.3 mm fraction diameter depending on the flow rate for "round obstacle"-type riffles

Visual analysis of figures in the figure 2 shows that at low rates (0.1-0.15 m/s) the microturbulence effect is practically absent, and the caked sand is not transported by the water flow. At the rates of 0.25-0.3 m/s and increase of the flow width (with a simultaneous increase of the filling) the microturbulence grows (appearance of the glare on the water surface) that contributes to the resuspension of sand and its transportation along the tray. Upon reaching a flow rate of 0.6-0.7 m/s an intense microturbulence and the almost complete disappearance of the ridges of sand are observed, except for the places of sand accumulations in trace amounts in stagnant areas behind the round obstacles. This fact demonstrates the need for improving the design of the obstacles and giving them a
more rounded shape. The experiments showed that fine sand is not completely removed from the tray in areas without obstacles even at water rates in the range of 0.7-0.8 m/s.

Similar series of experiments to study the dynamics of removal of sand inclusions on the same type of corrugated surface was made at the sand fraction diameter of 2.5 mm (figure 3). The fundamental difference between the results of the experiments was that the process of sand transportation has been more intensive compared to the previous series of experiments. If the water flow rate of 0.1-0.15 m/s shows a relatively efficient transport of impurities along the axis of the tray, the rate increase to 0.25-0.3 m/s shows transportation of the sand, which flows from the top area to the peripherical part of the tray axis. Only at 0.4-0.5 m/s rate sand begins to be transported again along the tray axis except for some clusters in the form of thick ridges, which are carried by the flow at a rate of 0.6 m/s. At the same time, it is necessary to note the complete identity of the previous series of experiments (velocity 0.6-0.7 m/s) as far as stagnation zones are concerned.

| Picture of the flow microturbulence zones and efficiency of removal of sandy impurities | Water flow rate, m/s |
|---|---|
| ![Image](image1.png) | 0.1-0.15 |
| ![Image](image2.png) | 0.25-0.3 |
| ![Image](image3.png) | 0.4-0.5 |
| ![Image](image4.png) | 0.6-0.7 |

**Figure 3.** Dynamics of changes in removal of impurities of 2.5 mm fraction diameter depending on the flow rate for 'round obstacle'-type riffles

Conclusions on visual assessment of the results of the experiments (see figures 2 and 3) can be reduced to the fact, that the obstacles need to be performed in a more rounded form with possible change of their dimensions and identification of the optimal distances from the tray axis to the center of the obstacles. Such studies are considered as a task of subsequent works. The purpose of these
studies is to identify the optimal surface relief of the tray, which enables the transporting ability of the flow at lower water flow rates.

Below are the results of experiments with other types of obstacles (figures 4-5).

| Picture of the flow microturbulence zones and efficiency of removal of sandy impurities | Water flow rate, m/s |
|---------------------------------------------------------------------------------------|---------------------|
| ![Image](image1.png)                                                                   | 0.1-0.15            |
| ![Image](image2.png)                                                                   | 0.25-0.3            |
| ![Image](image3.png)                                                                   | 0.4-0.5             |
| ![Image](image4.png)                                                                   | 0.6-0.7             |

**Figure 4.** Dynamics of changes in the removal of impurities of 0.1-0.3 mm fraction diameter depending on the flow rate for "cross bars with round obstacles"-type riffles
Picture of the flow microturbulence zones and efficiency of removal of sandy impurities

| Water flow rate, m/s |
|----------------------|
| 0.1-0.15             |
| 0.25-0.3             |
| 0.4-0.5              |
| 0.6-0.7              |

Figure 5. Dynamics of changes in the removal of impurities of 2.5 mm fraction diameter depending on the flow rate for "cross bars with round obstacles"-type riffles

The photos given in the figures 4-5 prove, that the nature of the vortex formation is identical to that one presented on the photos in figures 2 and 3. Effective removal of caked dirt in the form of sand is observed due to the phenomena of microturbulence within the flow range of 0.6-0.7 m/s. In the areas of the tray without obstacles, the removal of small fraction sand does not occur.

4. Conclusions
1. Using optical media complex investigations have been made on a special hydraulic bench to analyse microturbulence formation and the carrying capacity of the fluid flow in open trays having different internal surface relief.
2. The experiments have shown, that in the flow rate range of 0.1 – 0.7 m/s at a step-by-step increase of the rate, the riffled surface of the tray contributes to the microturbulence effect and transportation of sand fractions of 0.1-0.3 mm and 2.5 mm. The highest efficiency is observed at the rates of 0.6-0.7 m/s. In areas of the tray without riffs the removal of the fine fraction sand has not been observed.

3. The goal of subsequent experiments is the search for ways to improve the transporting ability of the flow in the trays with other types of riffled surfaces and their various geometric shapes, including hydrophobic surfaces. The goal of the research is the confirmation of field experiments using numerical methods.

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