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The study of the surface texture of pipes with the purpose of increasing their transporting capacity

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ABSTRACT

The results of exploratory research on the transportation of water and sand in specially designed laboratory and work benches including a platform with replaceable modular polymer elements (troughs) with artificial roughness are presented. The methodology of experiments on large benches with modular piped elements using photo- and film equipment as well as devices for determining velocity, filling and slope is presented. The nature of the turbulence zones with a different texture of the inner surfaces of the troughs in the form of obstructions of different height is revealed. The results of hydraulic experiments are presented in two modes: single-phase (water without foreign inclusions) and two-phase (water mixed with sand of different fractional composition). According to the results of experimental studies the areas of effective operation of modular troughs for sand transportation for various textures of artificial roughness of pipes of sewer systems were identified. The expediency of using corrugated inner walls of pipelines transporting wastewater for the efficient removal of sand belts settled on the bottom and walls of the pipes is substantiated.
Key words: gravity sewers, artificial pipe roughness, transporting capacity, modeling, microturbulence.

Introduction

Improving the flow transporting capacity of gravity sewers at low flow rates is one of the ways to ensure the efficiency of pipeline operation. This task is of particular relevance for small diameter pipes where a need to prevent the sedimentation of suspended solids (sand) in the trough parts of the pipeline network arises. In turn it is theoretically possible to prevent the sedimentation of suspended solids in the trough part of pipelines by making textured surfaces, for example, in the process of repair and rehabilitation of networks by pulling special flexible polymer liner with seamy surface through in pipes.

While transporting two-phase water flow containing highly concentrated suspended solids four modes of fluid flow can be observed depending on the flow rate [1; 2]. At low flow velocities sand settles and forms a dense and resistant to moving deposit layer at the bottom of the pipe. With an increase in the flow velocity sand starts moving in the form of a thin layer above the thickened sediments. With a further increase in velocity the thickened sediments accumulated at the bottom start disintegrating into slowly flowing dune-like formations that can enlarge both in area and volume in the form of vortex zones. As the velocity increases to self-cleaning (critical) level the sand particles almost completely become suspended in the fluid flow.

The four modes of fluid flow noted above were studied under conditions of alluvial river canals [3]. As an appendix to gravity sewers this was one of the basic elements in studying the processes of transporting wastewater containing suspended solids.

As indicated by previous experimental and theoretical studies in this area the threshold values determined theoretically in accordance with the velocity of bottom movements, as a rule, turn out to be higher than the values derived from visual observations [4; 5]. This discrepancy is to a large extent caused by the difference in the initial state of sand crumpled in the trough part of the pipe [6].

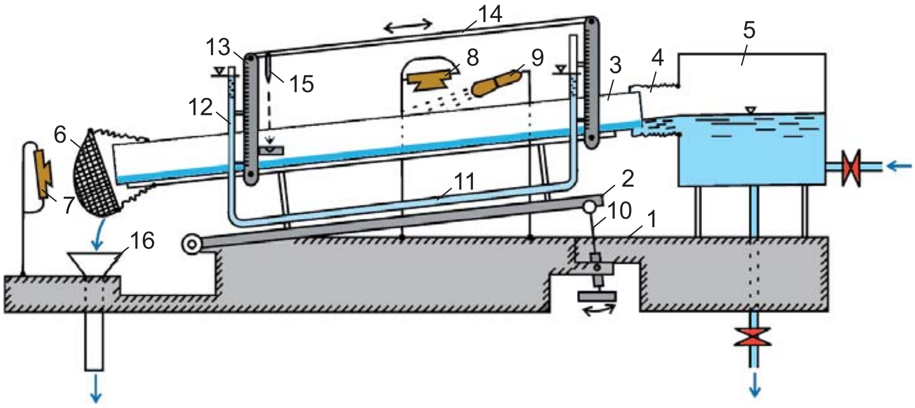


Fig. 1. Experimental hydraulic bench
1 – immovable frame; *2* – movable platform; *3* – open trough; *4* – rubber corrugated nipple; *5* – accumulating tank for fluid; *6* – dismountable meshy collector of foreign dispersed inclusions; *7*, *8* – cameras for front and coaxial shooting, respectively; *9* – light source; *10* – mechanical jack; *11* – water pipeline; *12* – flexible transparent interconnected tubes; *13* – movable measuring rulers; *14* – plank; *15* – laser plummet; *16* – receiving measuring jug

It should be noted that the formation of a crumpled thick layer of sediments in the trough part of the pipeline can cause certain risks, for example, increased friction losses, possible microbiological corrosion under the deposited layer as well as the need to increase the frequency of pipe cleanings with failure of the appropriate equipment which increases the cost of the operation of sewer networks [7; 8].

An increase in the efficiency of the washout of pollutants deposited on the trough part of the pipeline can be provided by the arrangement of conditions (development of measures) that enhance flow turbulization which contributes to the process of sediment transportation [9]. Thus, conducting live experiments to increase the transporting capacity of sewer networks can be considered as a hot topic of scientific research and an extremely important aspect in the development of projects of pipeline laying and rehabilitation using advanced systems for their diagnostics [10].

The wide possibilities of advanced technologies of manufacturing pipes and internal protective coatings made of composite materials with almost any surface structure facilitate the implementation of allotted tasks especially while introducing trenchless methods of rehabilitation of utility systems [11; 12] and using new maintenance materials [13].

Objectives of the study

The main objective of the experimental studies conducted at the department of "Water Supply and Wastewater Disposal" of Research Institution of MSUCE was to study the behavior of the fluid flow encircling artificially created point and linearly elongated obstructions. The essence of the tests was to study the behavior of single-phase and two-phase fluid flows while they flow around artificially created point and linearly elongated equal-sized and different-sized obstructions. The ultimate goal of live experiments was to identify the possible beneficial use of the vortex flow to increase the efficiency of the transporting capacity of the flow. In parallel the aim was to study the laminating (dissipative) effect of finely dispersed and coarse impurities (loose and coalescent sand) on vortex formation during the transition from laminar to turbulent flow [14; 15].

Exploratory live studies were carried out at certain ranges of fluid flow velocities using booster light (effect of light and shade) and were conditionally divided into two stages, including the study of the effect of various texture of the inner surface of pipelines on the following processes:

turbulence in single-phase flow at low filling, i. e., comparable to the height of obstructions, as well as in a wide range of filling;

turbulence in two-phase flow and transportation of sand with different mesh-size distribution.

Exploratory experimental studies of turbulence were carried out in a specially designed (patented) and mounted in the laboratory hydraulic bench in the form of open troughs with a diameter of 130 mm with the corresponding texture (corrugations) [16]. The experiments were accompanied by the effect of light and shade from a special lamp and were recorded with photo- and film equipment (Sony α550 Digital SLR Camera, DT SAM 1.8/50 Lens). A schematic representation of the test bench for the study of turbulence and flow transporting ability is presented in Fig. 1.

The results of the experiments and their interpretation

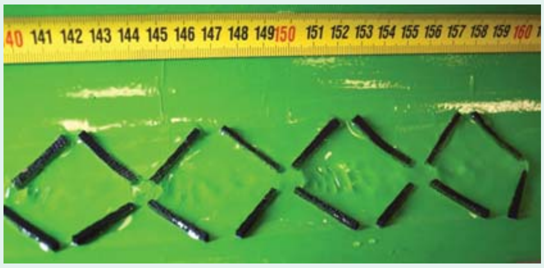
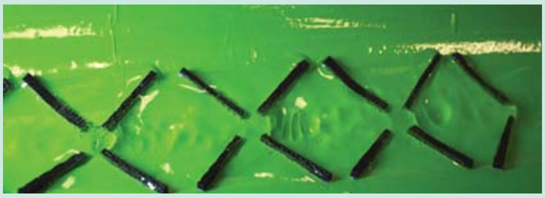
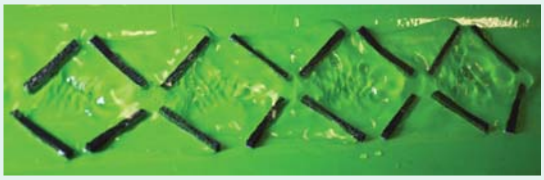
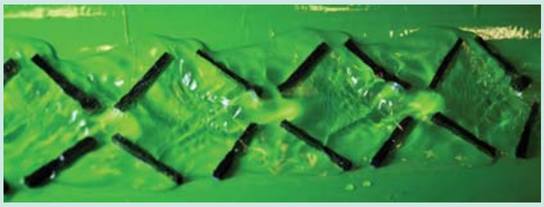
Low filling and relatively low fluid velocities in the trough (0.2–0.7 m/s) were a prerequisite for possible tracking emerging Karman streets. The nature of the resulting vortex cavities was subject to investigation, i. e., a description of the emerging vortices that could ultimately improve the efficiency of washing out pollutants that had previously settled on the trough or keep them from precipitating in the case of lower than self-cleaning velocities.

The corrugated surface in the trough part of the pipe was made by a set of metal and polymer things-obstructions (3D boxes with a semicircular, rectangular and pointed cross-section, polyhedra in the form of nuts, angles, pyramids, etc.). Obstructions were placed both in the center of the stream and with a relative shift (small and large) from the axis of the trough. This provided for identifying the size of the emerging vortices (type, length, width, area of the disturbed zone) both behind the object and upstream of the obstruction in the form of ripples. The total number of studied obstructions was 11 units. The experimental results were analyzed in detail to identify the optimal texture of the relief, the spacing and its orientation.

For illustrative purposes Fig. 2 shows pictures indicating the occurrence of flow turbulence caused by corrugated surfaces (Fig. 2, *a*), as well as the formation of Karman streets (Fig. 2, *b*). The experimental results are described in detail as the vortex formation pattern (coherent or vortex flow), and also with account of the size of vortices with averaged geometric dimensions of the disturbance zones (length and area before and behind the obstructions). It should be noted that the study of the water flow in the trough with various group obstructions provided for recording obvious turbulization of the flow in the velocity range 0.2–0.4 m and its intense manifestation at a velocity of 0.4 m/s, i. e., lower than self-cleaning what was used in subsequent experiments (Table 1). Moreover, the experiments provided for determining that almost any obstructions to one degree or another provoke flow microturbulence at fluid flow velocities below self-cleaning.

Experimental studies of the water flow of in the trough at high filling were accompanied by recording (using video- and photographic equipment) of vortex flows behind obstructions in the form of refraction (deformation) of the reflected light path. The strip (rope light) was made by a special light fixture with two lamps installed in parallel. The results of one of

Table 1

Coaxial picture of a trough with obstructions	Flow velocity, m/s
	< 0.2
	0.2
	0.4
	0.6
	> 0.7

a) b)

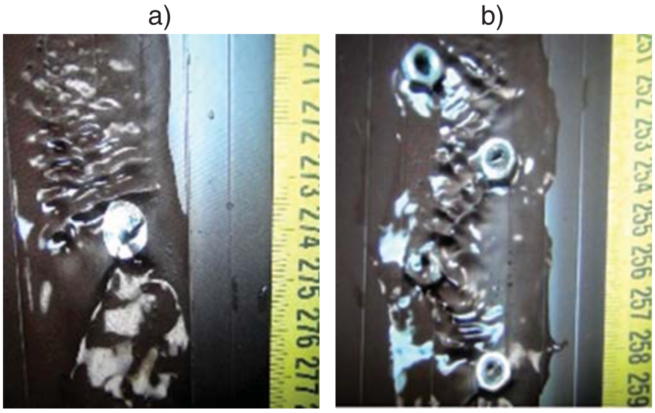
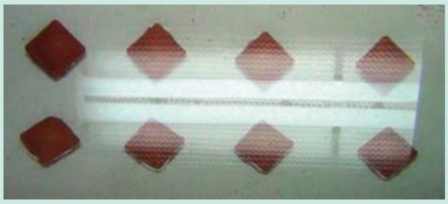
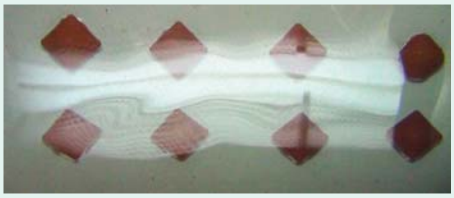


Fig. 2. Zones of flow turbulization before and behind the obstructions in the form of inverted ball segment
a – single obstruction; *b* – group obstructions (polyhedra)

Table 2

Experiment No.	Time T_{av}, s/m	Velocity V_{av}, m/s	Height h_{av}, mm	Fill h/d_{av}	Distortion (transformation)of light-and-dark reflected path
1	Original condition of the trough with obstructions in the form of pyramids				
2	15	0.066	20	0.154	
3	6	0.167	35	0.269	
4	4.5	0.222	40	0.308	
5	3.3	0.303	50	0.385	

the many experiments (obstructions in the form of a pyramid) are presented in Table 2.

Traced in the pictures (Table 2) is the contour of the so-called cord or the light-and-dark path that is refracted with an increase in the flow velocity: the signs of coherence, i.e. vortex separation have been already observed in the last line (No. 5).

The second stage of the experiments touched upon the issues of vortex formation in two-phase "water + sand" flow as well as the possibility of washing out sand with different particle size distribution from the trough, that is, impurities of 2.5, 1.5, and 0.1–0.3 mm fractions. In this case, configurations in the form of "direct" and "reverse herringbone", angles, pyramids, etc. were used as obstructions. The appropriate mass of sand in the form of a sand dune was distributed over a certain area along the length of the trough limited by obstructions.

The final stage of the experiments was the calculation of the relative transporting capacity of the flow at different locations and different types of obstructions: per unit area of the dune (ridge), mg/(s·cm^2); per unit length of the dune, mg/(s·cm) and through time. In parallel, in order to further compare and analyze the results of sand transportation efficiency experiments were carried out with the trough without obstacles. This allowed determining the difference between water flow velocities along the trough with sand with and without obstructions. During the experiments, time, velocity, and filling were recorded at which effective wash out of non-coherent (loose) sand mass was observed: it began to roll (slide) along the bottom line of the pipe or along the upper edge of the dune until it was completely removed and transferred to suspended state. The process of washing out balled up (coalesced) fine

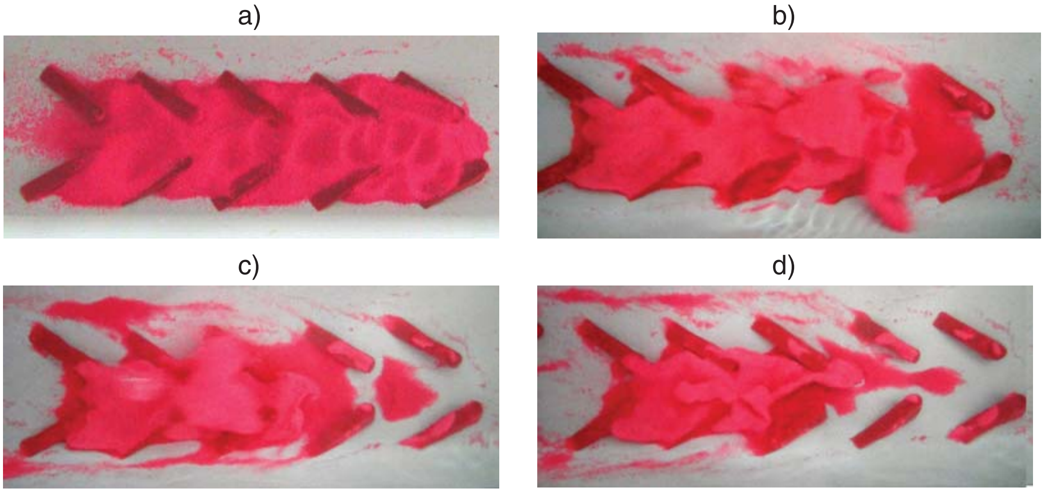


Fig. 3. Dynamic pattern of the state of the sand ridge

a, *b*, *c*, *d* – initial state and ridge transformation after 22, 45 and 62 s, respectively, until sand is completely washed out after 80 s

grains of sand was also studied where, in contrast to the loose sand mass effective wash out of sand grains in the form of layers was observed at filling of 0.3–0.4 and a velocity of the order of 0.4 m/s (Fig. 3)

CONCLUSIONS

1. Field experiments were conducted to study the hydraulic parameters of single-phase and two-phase flows in open troughs lacking textured surface and possessing corrugated structure in a wide range of filling (0.05–0.6) and velocities (0.1–0.6 m/s) of the fluid flow, and with the use of sand of various fractions (0.1–3 mm) as a transportation object.
2. It has been established that the most effective solution for transporting sand impurities in troughs is obstructions in the form of wedges with a pointed end to the flow or with a semicircular frontal one. The range of their transporting capacity in the range of velocities of 0.345–0.5 m/s and filling of 0.377–0.446 for sand fractions of 2.5–3 mm was, respectively, for the area of the dune 1.336–1.482 mg/(s·cm^2) and for the length of the dune 6.01–6.67 mg/ (s·cm^2).
3. In a trough without obstructions under the same conditions with obstructions in the form of wedges, for the complete wash out of sand ridges velocities of more than 0.588 m/s and filling of not less than 0.446 are required. In this case, the transporting capacity is, respectively, per unit of dune area 1.155 mg/(s·cm^2) and per unit length of the dune 5.2 mg/(s·cm^2) which is 18% less than in troughs with corrugated surface.
4. It was stated that in various situations related to the type and location of obstructions the transporting capacity of removing sand fractions of 0.1–0.3 mm compared to the fractions of 2.5–3 mm differs significantly. The difference per unit area is about 53.1%, and per unit length of the dune – 46.6%. Thus, finer fraction of sand is washed out more efficiently.
5. The experiments showed that obstructions in the form of pyramids and angles are ineffective since they did not provide complete wash out of sand ridges from the surface of the trough.
6. In prospect it is planned to evaluate the economic efficiency of reducing the number and duration of sewer network cleaning operations owing to more intensive washing out sand impurities with the availability of textured surfaces.

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