Technical innovations as a means of increasing the efficiency of technological equipment in modern production conditions

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Abstract. This article presents a study of the possibilities of technological equipment in municipal engineering, as well as technical innovations to improve its efficiency. The authors review the research on a hydraulic mode and resistances in a working body of a technological equipment. The research results are determined by the introduction of new technical solutions aimed at increasing the efficiency in the work of the Vodokanal enterprises. Improvement of technological equipment is as a result of the improved working conditions in the process of the water disposal system operation.

1 Introduction

The livelihoods of settlements and the ecological situation of water sources have a close relationship with the technical state of the water disposal system [14, 15]. The maintenance of the objects of this infrastructure is a complex multi-stage process aimed at maintaining the satisfactory sanitary condition of the residential areas. Operating conditions and increasing environmental requirements stipulate the continuous improvement of the equipment being employed in the technological regulations of the enterprises "Vodokanal." The introduction of modern technologies and the development of new technical solutions, aimed at increasing the technological potential, contributes to the improvement of operational qualities and increases the reliability of the water disposal system. At the same time, commensurability of energy costs and labor resources are also relevant, as well as capital investments.

The goal of expanding the capabilities of technological and technical equipment at the "Vodokanal" is:
- to comply with environmental standards;
- to improvs economic indicators;
- to ensure safe working conditions for personnel in the workplace.

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2 Literature review

The study of the causes of local resistance zones in the high-pressure hose of sewage channel washing machines and the peculiarities of operating conditions for special equipment is based on the analysis of scholarly publications and sources of regulatory and legal documentation. The object of the study is a useful model called the "Device for supporting and controlling the movement direction of the high-pressure hose of the sewage channel-flushing machines."

3 Materials and methods

The problems arising in the process of operation of sewage non-pressure pipelines are mainly related to the violation of a gravity-induced regime caused by clogging [3, 4, 8, 9, 12].

To eliminate such phenomena, there are a number of methods and technical means, the most widespread of which and the most effective is the erosion by water streams. This method, because of using special equipment, allows to eliminate clogs in sewer pipelines without using all sorts of ruffs and scrapers that have a negative effect on the internal walls of pipelines. Implementation of such technological tasks is carried out by specialized channel-flushing equipment mounted on the chassis of cars. The basis of their principle is the supply of water under high pressure on a special flexible high pressure hose (HPH), at the end of which a special nozzle with injectors is installed, through which the internal surfaces of the pipes are cleaned by directed water jets. The movement of the projectile in the pipeline is due to the reactive thrust created by the water streams emerging from the nozzle at a certain angle.

In the course of operation of the channel-flushing equipment, shortcomings in its configuration were revealed, essentially limiting the technological possibilities, which entail an increase in the material costs of operation, namely:

- An increased danger during the human descent into the sewage well for positioning the working organ [4, 5, 6, 13];
- A decrease in performance indicators when forming a zone of hydraulic resistance at the moment of its bending about the edge of the pipeline being treated;
- A reduction of the resource of the working body as a result of increased mechanical impact on the outer shell of the HPH;
- The lack of the ability to perform emergency work through a flooded section of the sewage line.

In addition, in the area of contact of the working element with the edge of the inlet of the pipeline, a region of local hydraulic resistances is formed, producing a loss of pressure:

- A sharp turn of a stream on 90˚;
- A partial overlapping of the flow.

On the basis of the laws of equilibrium of the dropping liquid, it is possible to calculate the hydraulic processes in the HPH (Figure 1), used as the working organ of sewage channel-flushing machines.
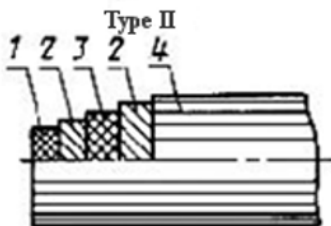
Fig.1. High pressure hose [7]: 1 - inner rubber layer; 2 - metal braiding; 3 - intermediate rubber layer; 4 - outer rubber layer.

Technical indicators of the DKT-275 working body [7, 8]:
-    Inside diameter of the hose - 25,0 mm;
-    Outer diameter of the hose - 38.1 mm (type I) and 39.7 mm (type II);
-    Outer diameter of the sleeve over the upper metal braid - 32.9 mm (type I) and 34.5 mm (type II);
-    The minimum bend radius is 300.0 mm (type I and type II)

The pressure loss for overcoming the hydraulic resistances hf is made up of:
-    Head loss by flow length (linear) - hl (losses spent on overcoming frictional resistance);
-    Local head losses - hj (losses caused by a sudden change in the configuration of flow boundaries).

Total head loss - hf is equal to the sum of all losses:

$$hf = hl + \Sigma hj \qquad (1)$$

Line resistance in the HPH at a length of 100.0 m of the DKT-275 sewer channel-flushing machines with a maximum pump capacity of 262.5 m [1, 8].

In some sections of the pipeline, where there are turns, local constrictions and expansion of the flow, local head losses occur, caused as well as losses due to the length of the work of friction forces.

At the entrance to the sewer pipe through the sewerage well in the HPH, a zone of additional local resistance is created by the HPH bend about the edge of the sewage pipeline and a sharp turn by 90˚, and it is 5.3 m.

In addition, with a sharp bending of the sleeve, a partial overlap of the liquid flow occurs. This phenomenon is comparable to the effect present in the operation of the Ludlo valve in a circular cylindrical tube.

Table 1. Summary of head loss in the HPH.

Indicators of head loss in the HPH of channel-washing machine DKT – 275	a/D degree of opening of Ludlo							
	0,25	0,3	0,4	0,5	0,6	0,7	0,8	0,9
	ξ - local resistance coefficient							
	30,0	22,0	12,0	5,3	2,8	1,5	0,8	0,3
Local head losses when the flow is blocked in the maximum	131,25	96,25	52,5	23,19	12,25	6,56	3,5	1,3

operating mode of the pump, m								
Local head losses when the flow is closed in a gentle pump operation mode, m	87,9	64,46	35,16	15,53	8,2	4,35	2,34	0,88
Total head loss in the maximum pump operating mode, m	399,05	364,05	320,3	290,99	280,05	274,36	271,3	269,1
Total head loss with gentle pump operation, m	273,88	250,44	221,14	201,51	194,18	190,33	188,32	186,86

Taking into account the unpredictability of the volume of internal sediments and sludge in the pipeline, creating a load in the HPH bending zone during the tractive effort created by the channel washer's drum, the entire range of values characterizing the degree of opening of the Ludlo gate valve (Table 1) [1].

Thus, the local pressure losses in the HPH of the channel-flushing machine with the traction forces generated by the drum vary considerably. Depending on the level of deposits in the pipeline and its length, the load on the outer walls of the working member, created by frictional forces upon contact of the shell with the washed out slurry, increases. In this case, the mechanical action on the zone of local resistance ("a sharp turn by 90°'") proportionately increases, causing changes in the cross section of the sleeve with subsequent partial overlapping of the flow. As a result, pressure drop occurs on the nozzles of the working element, thereby reducing the efficiency of removing sludge and deposits from the pipeline. Such situations in practice can lead to jamming of the working element in the pipeline and its loss, creating, at the same time, the risk of blocking the sewage line.

For the operation of the URACA KD716GS high-pressure pump (Table 2 [10]) in the gentle mode of the DKT-275 sewage channel washers, in accordance with [8], a coefficient of 0.8 is recommended, in which the condition P>10.0 MPa is true.

Proceeding from this, the linear resistances in the HPH at Pmax=16.0 MPa and the length of the hose 100.0 m will correspond to 182.65 m. The local resistance caused by a sharp rotation of the flow in the pipeline by 90° will correspond to 3.33 m.

From the studies carried out, it is possible to conclude that local resistance (caused by a sudden rotation of the flow in a hydraulic line by 90° and partial overlapping of the channel) are influenced by the efficiency of sewer channel-flushing machines in eliminating blockages and preventive washing of sewage pipelines.

Figure 2 clearly shows the operation modes of the DKT-275 channel-flushing machine, depending on the sum of local and linear resistance in the HPH, determined by operating conditions and characterized as unstable.
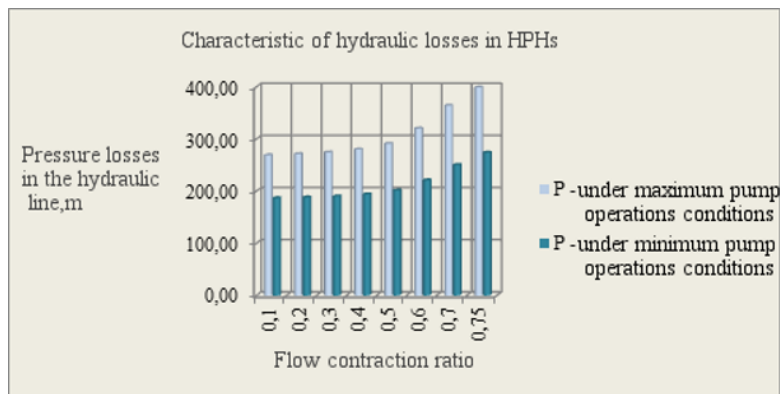
Fig. 2. Characteristics of hydraulic losses in the HPH.

4 Results and analysis

When operating the channel-flushing equipment, it was noted the need to create conditions that allow reducing local hydraulic resistance and stabilizing their impact on the working body. Particular attention is paid to the working area of increased danger associated with technological activities in the sewage well.

Given a set of operating components, at the Department of Engineering Communications and Life Support Systems of the Irkutsk National Research State Universty was designed and built a prototype of the device for supporting and controlling movement directions of the high pressure hose of the sewage canal and washing machines [9].

The claimed device patent No. 173247 "Device for supporting and controlling the movement direction of the high-pressure hose of the sewage channel-flushing machines" is aimed at improving labor safety and performance conditions in accordance with GOST 6286-73: the local resistance section of " a sharp turn by 90°" in the HPH is to be transformed into a zone of "a smooth turn to 90°" with the possibility of fixing the minimum bend radius, which is 300.0 mm.

These hydraulic conditions, according to [2], look as follows, where the local resistance coefficient ξ_a is determined from the dependence

$$\xi_a = \xi_{90°} \cdot a = 0{,}065 \cdot 1 = 0{,}065, \qquad (2)$$

where: $\xi_{90°}$ – the coefficient of resistance when rotating by 90˚; a – the coefficient depending on the rotation angle.

The coefficient $\xi_{90°}$ depends on R/d (the ratio of the radius of curvature to the diameter of the pipe) and the coefficient of resistance along the length of the pipeline λ and can be determined from the formulas of A. D. Altshulia [2]:

$$\xi_{90°} = [0{,}20 + 0{,}001(100\lambda)^8]\sqrt{\frac{d}{R}} = [(100 \cdot 0{,}0016)^8 \cdot 0{,}001 + 0{,}2] \cdot 0{,}2 = 0{,}065 \quad (3)$$

$$hj = \xi_j \frac{v^2}{2g} = 0{,}065 \frac{7{,}41^2}{2g} = 0{,}18 \text{ м} \qquad (4)$$

Based on the results of the developed utility model, the value of the total head loss *hf* in the HPH of the DKT-275 sewer channel-washing machine is 182.83 m.

Such a condition makes it possible to reduce the working pressure created by the pump to the required limit, which allows performing the technological function to the working body. With the existing indicators and taking into account the total head losses in the HPH at the moment of performing the technological operations with the maximum load in the sparing mode according to [8], the coefficient of 0.8 is applied to the high-pressure pump, which corresponds to P = 12.8 MPa. Taking into account the maximum pressure losses in the gentle operating mode (2.74 MPa), the required pressure for the operation of the nozzles is 10.06 MPa, which is permissible according to [8]. The general hydraulic losses in the conditions of applying the useful model [9] allow to reduce the factor of sparing mode for the high-pressure pump of the DKT-275 channel-flushing machines to 0.75.

In this case, the pressure losses along the flow length (linear) according to [1] will be:

$$hl = \lambda \frac{l}{d} \frac{v^2}{2g} = 0{,}0163 \cdot \frac{100}{0{,}025} \cdot \frac{7{,}41^2}{2 \cdot 9{,}8} = 182{,}65 \text{ м}, \tag{5}$$

where the coefficient of hydraulic friction λ, according to [1], is determined by the Blasius formula:

$$\lambda = \frac{0{,}3164}{Re_D^{0{,}25}} = \frac{0{,}3164}{(1{,}42 \cdot 10^5)^{0{,}25}} = \frac{0{,}3164}{19{,}1} = 0{,}0163, \tag{6}$$

Reynolds number is in accordance with [1]:

$$Re_D = \frac{vD}{v} = \frac{7{,}41 \cdot 2{,}5}{0{,}01306} = 1{,}42 \cdot 10^5, \tag{7}$$

where *V* is the coefficient of kinematic viscosity of water at a temperature of 100°C in accordance with [1]:

$$v = 0{,}01306 \ cm^2/\text{с} . \tag{8}$$

Thus, the maximum pressure of the DKT-275 channel-flushing equipment of 16.0 MPa is expedient to be reduced by 25%, which would be 12.0 MPa, while the *P* condition (HPH before the nozzle: 10.44 MPa>10 MPa) is fulfilled. Taking into account the use of a useful model, the efficiency of using the DKT-275 sewer channel-washing machine is increased by reducing operating costs as a result of lowering the operating pressure created by the plunger pump by 5.0% of the pressure recommended by the manufacturer.

The main characteristic of piston pumps is the relationship between its pressure and delivery (pressure). In this case, the feed at a pump with certain geometric parameters is theoretically independent of pressure. This means that for a given speed, the feed is constant and the same for all heads.
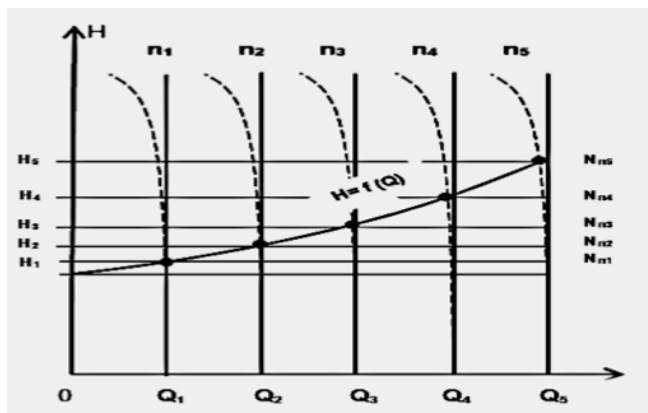
Fig. 3. Characteristics of piston pumps.

The characteristics of a piston pump at a variable speed are represented by the family of straight lines parallel to the ordinate axis. The actual characteristics deviate from the theoretical one (as shown by the dashed lines in Fig. 3). This deviation is explained by the fact that when the head is increased, the volumetric efficiency of the pump decreases due to increased leakage [11].

If the pump receives a new speed $n_2 > n_1$, its feed rate increases in proportion to the rotational speed, and the characteristic takea a new position, corresponding to n_2 (Fig. 3). Similarly, characteristics for the rotation frequencies: $n_3 > n_2$, $n_4 > n_3$, $n_5 > n_4$ [11].

The characteristics of H = f (Q) show that for a given speed of rotation, the piston pump can create different heads. In this case, it will consume different power.

Table 2. Technical data of the URACA KD716GS high pressure plunger pump**.**

Parameters of the URACA KD716GS high pressure plunger pump (version: A - 1					
Diameter of the plunger, mm	Plunger stroke, mm		Gear ratio		Developing head, MPa
60	70		3,23		160
Characteristics of the pump with an efficiency of 98%					
Number of turns of the drive, rpm	1000	1100	1200	1300	1400	1500
Number of pump revolutions, rpm	301	331	362	392	422	452
Pump capacity, m³ / h	10,5	11,55	112,6	13,68	14,73	15,78
Power consumption of the pump, kW · h	56	62	67	72	78	84

In the process of using the useful model, the device for supporting and controlling the direction of movement of the high-pressure hose of the sewage channel-flushing machines was noted:
-   No need for a person to run into the sewer well for positioning the working body;
-   Reduction of mechanical impact on the outer shell of the HPH;
-   Increasing efficiency of the technological process due to improvement of ergonomic conditions and additional possibilities.

The developed utility model (Figure 4) refers to the municipal engineering industry, the additional equipment of the channel-flushing machines, which is designed to support and control the direction of movement of the high-pressure hose in the sewage pipeline. The aim

of the claimed technical solution is to expand the functionality and improve the efficiency of process equipment.
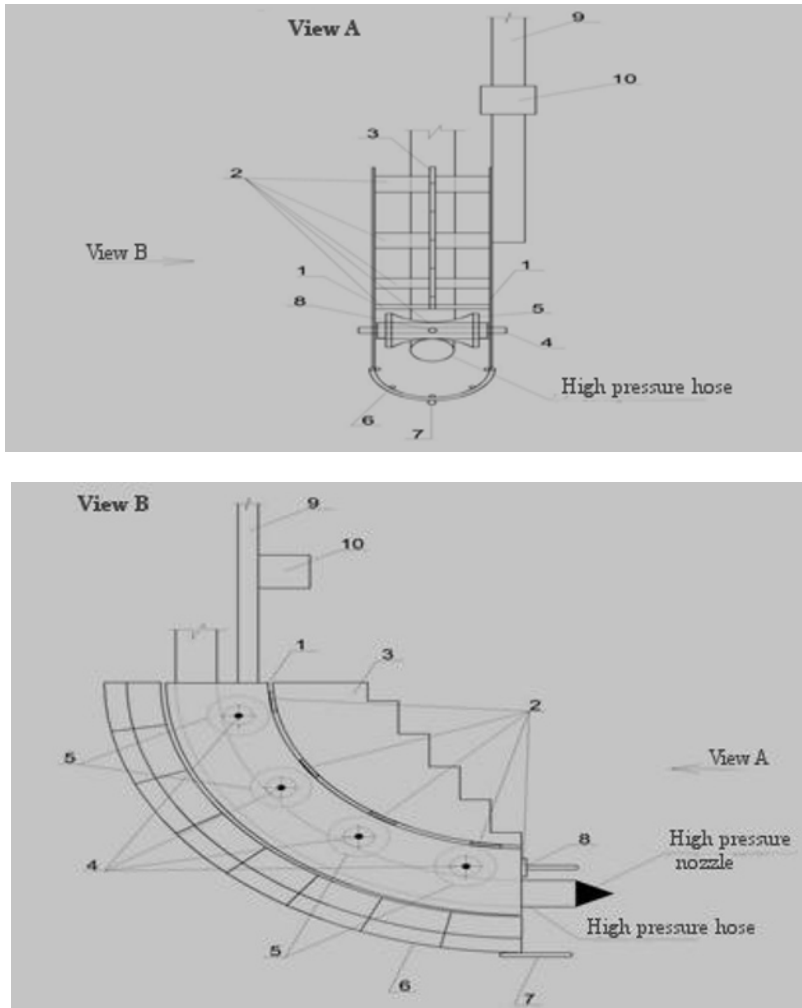

Fig. 4. Device for supporting and controlling the direction of movement of the high-pressure hose of the sewage channel-flushing machines [9].

The technical result of the useful model is achieved by means of a device for supporting and guiding the movement of the high-pressure hose of the sewage channel-flushing machines. This device consists of metal plates and metal pins connected together. They are the supporting axes for the rollers, which perform the direct function of supporting the high-pressure hose. The device also has a bar allowing to perform works on washing the sewer line without letting the person into the well, and also makes it possible to carry out measures to eliminate the blockage through the flooded well. Other parts of the device include (a) a support jig that allows the device to be held in the gravity line of the gravity pipeline, (b) metal pins to hold the device in a gravity pipeline, (c) a shell consisting of transverse and longitudinal bars of a metal circle, providing a high-pressure hose with a nozzle, (d) an

illumination being placed on the rod and consisting of an electric power supply element and a light source for reviewing the work performed at low illumination (Figure 4) [9].

The device works as follows. The high-pressure hose with the necessary nozzle installed on it is placed in the device between the metal plates (1) and the shell (6). With the help of the rod (9), the device is placed in the well and fixed in the pipeline by means of pins (7, 8) or by means of a conductor (3) (depending on the internal diameter of the pipeline) and held by the rod (9) for the whole period of the pipeline flushing. In low light, the backlight (10) located on the rod (9) turns on and allows to improve the view in the well. Due to the reactive thrust created by the water streams, the high-pressure hose changes its direction of travel from vertical to horizontal; a bending in the transition zone into the pipeline is carried out along the trajectory defined by the support rollers (5) in accordance with the necessary parameters. When the device performs a controlled support function, the bend of the high-pressure hose about the pipeline edge is eliminated, thereby eliminating the additional hydraulic resistances adversely affecting the efficiency of the hydrodynamic flushing, as well as reducing the frictional effect on the hose shell of the high-pressure hose and increasing the service life of the hose [9].

5 Conclusions

In the conditions of economic development, any modern production requires constant modernization of equipment and improvement of technological processes. At the same time, special attention should be paid to safety in the workplace. The operation of sewerage networks is conditioned by human contact with the aggressive environment of sewage, the concentration of toxic substances, which depends on the type of activity and infrastructure of the users, as well as the hydraulic parameters of the line. Technological processes, from which it is impossible to exclude completely the labor activity of a person connected with an increased danger, must be regarded as an object of continuous study.

Analysis of production activity allows to identify hidden production reserves, determine the true capabilities of the equipment used in the technological process, and create the ground for developing/implementing technical innovations aimed at increasing the economic efficiency of the enterprise as a whole.

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