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DEVELOPMENT AND STUDY OF HYDROMECHANICAL METHOD FOR CLEANING SEWAGE COLLECTORS FROM CONTAMINATION

D. Goncharenko
Doctor of Technical Sciences, Professor*
E-mail: gonch@kstuca.kharkov.ua
S. Zabelin
PhD, Head of Operational Area
Operational area of the Industrial district
CE «Kharkovvodokanal»
Shevchenko str., 2, Kharkiv, Ukraine, 61013
E-mail: zzzmmm@rambler.ru
A. Aleinikova
PhD, Assistant*
E-mail: gabriel222@rambler.ru
A. Anishchenko
PhD, Associate Professor
Department of mechanization
of construction processes**
E-mail: Aanishchenko@ukr.net
R. Hudilin
Postgraduate student*
E-mail: r.i.gudilin@gmail.com
*Department of building technology**
**Kharkiv National University of
Construction and Architecture
Sumskaya str., 40, Kharkiv, Ukraine, 61002

У зв'язку зі станом сучасних каналізаційних колекторів існує велика потреба в швидкому та якісному очищенні для подальшої експлуатації. Для підвищення довговічності розподільчої системи проводять розробки нових технологій їх ремонту та відновлення, що дає змогу забезпечити її стале функціонування, як наслідок – надання послуг безперервного постачання питної води та водовідведення для забезпечення високої якості життя населення. Перспективним є підвищення довговічності розподільчої системи шляхом розробки альтернативних технологій ремонту з економічної точки зору, що дасть змогу забезпечити її стале функціонування в умовах обмеженого фінансування.

Запропонована конструкція ковша при очищенні каналізаційних колекторів дала можливість виявлення оптимального варіанту при використанні однієї конструкції в різних умовах.

Запропоновано нову конструкцію ковша, яка дає змогу проводити очищення каналізаційних колекторів як окремо чисто механічним способом, так з додатковим використанням гідравлічного способу. Завдяки такому комбінованому способу можна очищати засмічення, які окремо кожен із способів не зможе забезпечити з точки зору досягнення якісного очищення при різних технічних та економічних умовах.

Представлено та обґрунтовано цілеспрямованість використання запропонованого методу очищення каналізаційних колекторів з використанням конструкції ковша з комбінованим способом роботи.

Приведено приклади використання нового методу чистки колекторів з використанням нової конструкції ковша. Отримані показники підтверджують якість очищення каналізаційних колекторів при проведення роботи в різних умовах, як технічних (діаметр, довжина та вид матеріалу колектору, ступінь та характер засмічень), так і економічних (тривалість, затрати енергії та води).

Завдяки використанню такого метода досягнуто очищення 75...85 % каналізаційних колекторів та трубопроводів, що підтверджують його ефективність, і дає можливість економії за тривалістю виконання робіт, а також у ресурсо-енергетичних витратах при проведенні даних робіт

Ключові слова: каналізаційний колектор, каналізаційний трубопровід, мережа водовідведення, метод очищення, муловий осад

1. Introduction

Centralized sewage disposal is a complex combined system consisting of sewer networks, headers, sewer tunnels, treatment facilities of various capacities, etc. Currently, sewage disposal systems in Eastern European cities are operated by various utility enterprises that fulfill their socio-economic obligations on the verge of technical and organizational capabilities, as evidenced by:

– technical vector: high depreciation of fixed production assets, in particular, sewage networks of various diameters;

– economic vector: unstable economic situation in countries and subsidized nature of the sector;

– organizational and managerial vector: imperfect management system requiring reformation.

Having considered the structure of distribution networks of the sewage disposal systems of Eastern European cities in terms of technical components, the following conclusions can be drawn [1]:

– network length growth depending on duration of their operation (e.g. networks length is 5...16 km for duration from 5 to 15 years, 600...900 km and more for 50 and more years);

– wear degree depends on the network length growth (e.g. wear of networks was 70...75 % in 2008...2010 and 80...85 % in 2014...2016;

– the most popular material types for building sewage networks: ceramics, reinforced concrete, cast iron, steel, brick, asbestos cement and plastic;

– pipe diameter depends on the purpose of the sewage disposal network: Ø100...300 mm (49 %), Ø300...500 mm

(45 %), Ø500...900 mm (2 %), Ø900...1500 mm (1 %), Ø1500...2500 mm (3 %).

Growth of the volume of restoration works on underground utilities causes tightening of requirements to ecological safety of construction works during operation and repair of distribution networks in conditions of existing urban housing. Accordingly, it is necessary to use technical means to ensure conduction of works by the most appropriate methods from the technical and economic points of view [4, 5].

The number of water supply and sewage disposal pipelines being in emergency conditions is approximately 38.5 % and in some regions of Eastern Europe, it exceeds 50 % of the total length which significantly affects quality of water supply services in terms of drinking water quality and its sustainable supply. In late 1990s, the average number of emergency damaged pipelines per unit length in the Eastern European cities was about two times more than that in the Western Europe, the specific number of accidents increased in about ten times in the last decade. Predicted wear of the main Eastern European water and sewer pipelines will be about 90 % in the coming years.

Development of enterprises operating the water supply and sewage systems is aimed at extension of service life of the distribution systems by developing new technologies for their repair and restoration. This will ensure sustainable operation of these systems and as a consequence, provision of continuous supply of drinking water and sewage disposal to improve life quality for the population.

Analysis of state of sewer pipelines and headers has shown very high importance of their careful cleaning. Having considered the existing methods of cleaning, it can be concluded that different cleaning methods are used for different pipeline types (diameter, material, purpose). They are effective only for concrete conditions. In this regard, there is a need for such efficient cleaning method that would be suitable for pipes of various diameters (from small to very large) and various purposes. It is also necessary to have equipment able to remove sediments of various types.

This indicates that the subject of studies aimed at high-quality, rapid and cost-effective cleaning of sewage headers of various diameters, purposes, material types and any degree of foulness is of high relevance.

2. Literature review and problem statement

The studies on service reliability of pipelines show that preference is given presently to no-dig recovery technologies which are more economical than traditional ones (that is, with excavation). The results of long years of studies on causes of failure of pipelines, impact of their technical condition on water quality and the ways of improvement of their operating life are consolidated in [6]. The issue of restoration of headers built from prefabricated reinforced concrete components with the use multicomponent building materials was considered in [7]. The issues of filling the annular gaps with a multicomponent mixture to reduce friction of surfaces and the measures of grounding in repair of utilities, especially the relining technology, are given particular attention in [8]. Use of polyethylene pipes and polymer liners in restoration of pipelines in the course of their operation was studied in [9]. These studies have considered and offered options of restoration and assessment of the pipes state but no examples of cleaning existing pipes are given and only their replacement and repair are considered.

No-dig methods of pipe restoration are constantly being improved in order to raise their efficiency. Point repair of pipelines using mechanical sleeves of Quick Lock polymer is illustrated in [10]. Improvement of the environmental component of application of no-dig technologies is considered in [11]. This mechanical point repair system is used for internal repair of small-diameter steel pipes.

Much attention is paid to modeling the processes of repair and operation of pipelines. Models of failure of stable operation of distribution networks for its further forecasting were proposed in [12]. Based on statistical data, it is possible to develop regression models that can forecast structural and operating conditions of pipelines [13]. This modeling is only used for more than 500 mm dia. water pipelines.

Concerning study of the factors influencing service life of distribution networks and technical and economic indicators of work execution, it should be noted the following:

– studies devoted to the issues of corrosion protection of reinforced concrete headers are given in [14];

– numerical study of longitudinal bending in pipes exposed to lateral earth movement presented in [15] plays an important role in the execution of construction works.

In the studies considered, limitations are imposed on the pipe diameter and the type of material from which pipes are made as well as on the pipeline purpose, i.e. water supply or sewage disposal systems. The engineering requirements specify parameters for choosing one or another method of repair and not just one parameter for all methods.

It can be concluded from analysis of the known damage control works that mechanical and hydraulic methods are mainly used in cleaning the sewer headers.

Rothenberger GmbH (Rothenberger, Germany) [16] proposes to use the method of hydrodynamic flushing of pipelines to eliminate remains of sediment destroyed by the mechanical cleaning method. Many types of foul, such as fat and silt sediments, are most effectively eliminated by the hydrodynamic method. Such compact high-pressure devices operate on alternating current for cleaning 150 to 200 mm dia. pipelines, up to 40 meters in length, as well as for cleaning surfaces of vehicles, machinery, buildings and foundations. They have a function of water suction (water head up to 2 m).

Hellmers GmbH (Germany) [17] offers the use of a pipe flushing machine of a combined type for flushing water supply and sewerage pipelines. The machine is mounted on the MAN truck chassis and is used for labor-intensive washing operations where the fully automatic cleaning process provides continuous recirculation of flushing water.

In addition to the recirculation work, the machine can also perform flushing of sewage pipes with diameters from 100 to 1000 mm.

Mechanical method for cleaning pipelines is widely used in Ukraine.

A chain carousel is used in the centrifugation method which enables cleaning of 125...450 mm dia. headers at a recommended pump capacity of 120 l/100 bar [18]. With the help of appropriate additional equipment, it is possible to use it in up to 2,000 mm dia. headers at a recommended pump capacity of 260 l/100 bar. In this process, sediments are broken and washed away in the direction of cleaning advance. Uniform motion of the centrifugal mechanism is provided by means of a winch. The carousel guide carriage consists of 5 individually adjustable guide skids. Due to the design of the chain carousels, extremely sharp self-sharpening chains do not cause damage to the pipe surface making it possible to use this device in pipes of any material.

It should be noted that not all operating enterprises have diagnostic complexes including television units for inspection of underground sewer networks.

The pulling method uses scraping and cutting components for continuous flow-type flushing of pipelines [2] when hard sediments are scraped off and washed away. For this method, a special winch and traction ropes are needed.

Drawbacks of such device include difficulties encountered in the process of high-quality wall cleaning and inability to clean complicated pipeline systems. It is used only for water pipelines. This equipment is highly priced and consumes much energy in its operation.

The hydrodynamic method of cleaning sewage pipelines is becoming increasingly popular. It uses a hydraulic machine with special nozzles that create point pressure in the pipeline [18]. Due to this, slurry sediments are washed off the pipeline walls.

The hydraulic machine can be used only at temperatures down to −5 °C. It is a disadvantage limiting its use in certain climatic conditions. In addition, the hydrodynamic method is most effective for sewage pipelines with diameters not exceeding 500 mm. For pipelines with diameters above 500 mm as well as for very silted pipelines, this method does not ensure complete elimination of silt sediments. The constant use of high-pressure liquid makes this method uneconomical because of large energy consumption and costs.

A flow restricting device is used in the hydrodynamic method described in [19]. The existing sewage stream creates turbulence in the pipe and as a result, the dirt is suspended and moved downstream where it is removed and delivered to the debris disposal station. When using this method, it is possible to clean the system with access to only few sewer manholes in the system.

Drawbacks of using the hydrodynamic cleaning method include its high cost of work execution, water supply and electricity.

Environmentally friendly repair of sewer systems is considered in [20]. The proposed method provides placement of prefabricated sandwich panels or composite casings in the existing sewer system. It can increase service life of headers but does not ensure protection against contaminants and their destruction inside the pipe. Repair works can be carried out only after thorough cleaning of the headers.

Analysis of the existing methods of cleaning the sewage headers and pipes as well as the causes of their occurrence [21] makes it possible to conclude that cleaning is mainly conducted by two methods: mechanical and hydrodynamic. Both versions can be effective only under limited conditions, they require large investments, time and labor expenditures.

A promising version of overcoming the described shortcomings in cleaning sewage headers is extension of service life of the distribution sewerage systems. Development of alternative repair techniques will ensure their stable functioning under conditions of limited financing which will be economically advantageous compared to the existing means requiring large investments.

3. The aim and objectives of the study

This study objective was to develop and test a new method for cleaning sewage headers with various degrees of foulness which will be applied at various technical constraints and reduce restoration time and energy costs.

To achieve the objective, the following tasks were set:

– to propose a method for cleaning sewage headers using a bucket operated in a combined mode;

– to carry out study on the proposed bucket design in cleaning headers with the use of the new method;

– to conduct a study of the factors affecting efficiency of the sewage header cleaning by the proposed method with a new bucket design;

– to obtain technical and economic results of application of the new method for cleaning the sewer headers.

4. Materials and methods used in the study of effective cleaning of the sewage headers

4. 1. Choice of equipment for cleaning the sewage headers

Having considered the above methods of cleaning the sewage headers, we can conclude that the mechanical method of pipeline cleaning is the best, however, merits of the hydrodynamic method should not be excluded as well. Accordingly, there is a question how to choose the equipment for such works.

First, let us consider the metal bucket proposed in [22]. The bucket is made in the form of a hollow half-cylinder with two cross beams attached to its ends for connection with ropes. At one end of the half-cylinder, there is a bridge with a semicircle valve with ability to turn by 90°. The valve opens during cleaning when the bucket moves forward and when bucket is full and moves backward, it closes. This bucket design enables elimination of only silt sediments in small areas.

If more than 400 mm dia. sewage headers are cleaned and there are stone sediments alongside silt, such a bucket will not work.

To accomplish the set task, it is proposed to fit up the front end of the bucket with knives to cut off hard sediments and a steel bar-pipe to feed pressurized working fluid through the holes [24].

The bucket for cleaning the sewer headers (Fig. 1) [23] consists of the bucket body 1 which looks like a hollow metal half-cylinder. There are holes 2 in the sides of the bucket for fastening the traction rope drawn from the starting pit and holes 6, 7 for fastening the traction rope grawn from the target pit. The steel bar-pipe 3 for feeding pressurized working liquid is fixed to the inner surface of the bucket 1. In the front part of the body, there are holes 4 in the rod-pipe 3 for supplying working fluid under pressure and knives 5 for cutting sediments.

This design makes it possible to perform work both merely in a mechanical way and with an additional supply of pressurized fluid which is inherent for the hydrodynamic method. Also, the proposed design will give an opportunity of saving resources, operating time and labor in operation.

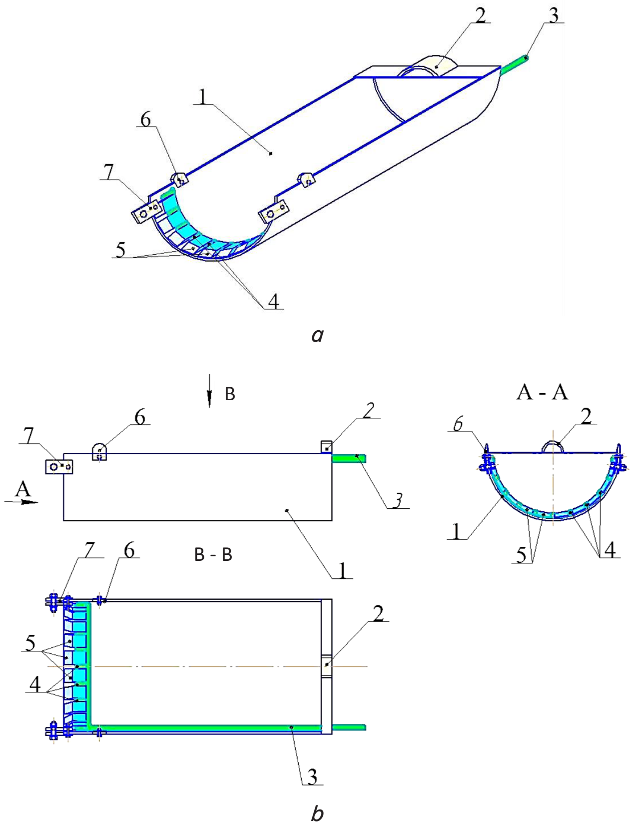

Fig. 1. The sewer cleaning bucket: general view (*a*); top view of the bucket (*b*); body 1; holes 2 for fastening the traction rope from the starting pit; steel rod-pipe 3; openings 4 for supplying pressurized working fluid; cutter knives 5; holes 6, 7 for fastening the traction rope from the target pit

4.2. Cleaning of the sewer headers using the proposed method

The method considered in [24] was taken as a basis for cleaning the sewage headers. The method is implemented as follows. First, three consecutive sewage wells are prepared (Fig. 2): the first well 1, the middle well 2 and the third well 3. To do this, open manholes and check condition of the well bottoms. Thrusts 4 with pulleys 5 are installed in the first and the third sewage wells 1, 3. Winches 6 are installed on the surface above the first and the third wells 1, 3, ropes 7 are drawn from both winches to the middle well 2 and the metal bucket 8 is lowered there.

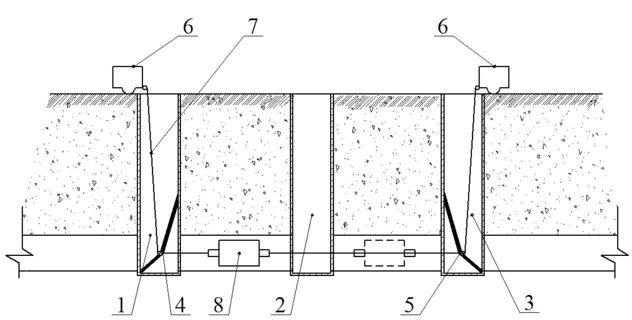

Fig. 2. The method of sewer cleaning: well 1; well 2; well 3; thrusts 4; pulleys 5; winches 6; rope 7; metal bucket 8

The bucket 8 is pulled forward towards the first well 1 by a distance that ensures its filling. In this this motion, the bucket 8 cuts the silty layers and is completely filled. The filled bucket 8 is then pulled back into the middle well 2 where sediment is unloaded from it.

When the middle well is cleaned of sediment, operation of pulling the bucket 8 in the direction of the first well is repeated until the sewage pipeline is completely cleaned of sediment. After that, the same operations are repeated in direction of the third well.

This method is effective only for pipelines with diameter not more than 500 mm. If diameter is larger, then before carrying out the work, it is first necessary to discharge water from the sewage wells and the pipeline.

Therefore, we consider that such cleaning method cannot be used in large diameter headers with complex contaminants. It is less economical in terms of technical parameters.

The proposed method using the bucket of new design will be more effective to clean the sewer headers. It will make it possible to reduce duration of the cleaning operation. This method can be applied in any conditions.

The improvement of the cleaning method with the use of the bucket of new design consists in that when the bucket is lowered in the sewer header, it begins to move forward using a winch from the starting pit to the target one. Sediments in the pit are scraped with knives. If the cleaning process is complicated, pressurized liquid is supplied from the holes to facilitate disintegration of sediments and operation for the blades. The cleaning process is repeated until the sewage header is completely cleaned.

The advantages of using this method with the proposed bucket design consists in its multifunctionality in work depending on the degree of foulness. The process of cleaning the header can be conducted purely mechanically, and in some pipeline sections where there is silt sediment combined with hard stone sediments, cleaning with feeding pressurized liquid is highly cost-beneficial. That is, single equipment can be used in a pipeline section to save time, resources and energy.

5. Results obtained in the study of the method for cleaning the sewer headers using the proposed bucket

The proposed method for cleaning the sewage headers using a new bucket design (Fig. 1) was applied at various utility sites with different parameters and working conditions:

– diameter: from 600 to 900 mm;

– header materials: steel, reinforced concrete, bricks;

– cross-section shape: round, oval;

– nature of the header damage (pitting, through corrosion, damage of the butt joint, damage of the trough part of the header, corrosion of the arch part of the header, corrosion of the well walls);

– method of damage elimination (local repair, applying steel couplings, sealing of the butt joint, partial pipe replacement, application of corrosion protection coatings).

Appearance of headers at different sites and recovery stages is shown in Fig. 3–5. The main characteristics of the facilities and the results of restoring conveyance capacity and cleaning of the sewage headers are given in Table 1 (RF=recovered facility).

An example of the work performed by the proposed method is cleaning of a sewage pipeline with pipe diameter of 600 mm, section length of 460 m laid along Frunze Avenue from Shcherbakova Street to Volochayevska Street in the city of Kharkiv. Characteristics of this recovered facility are given in Table 1 (RF1). The pipeline was in an emergency state, 50 % filled with silt sediments. Cleaning was carried out as shown by the diagram in Fig. 2. The distance to which the metal bucket was pulled in direction of the first or the third well was measured with the electric winch previously installed above the third well. The pipeline was completely cleaned of silt sediments and large clogs within four months. The purification efficiency was 100 % (Fig. 3).

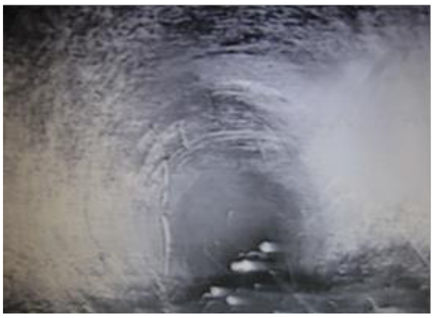

Fig. 3. Tele-inspection of the sewer header in Frunze Avenue after cleaning by the method proposed by the author (RF1, Kharkiv, Ukraine, 2017)

The experience of restoring conveyance capacity of the sewage header built from clinker bricks with a complex cross-section in Severin Pototsky Street, the city of Kharkiv, is of particular interest. The main technical characteristics of the recovered facility are given in Table 1, RF5. The header was cleaned by the method proposed by the authors for cleaning the sewer headers using the new bucket design. Complexity of the work consisted in the presence of a turn in the header path and absence of a well in this area. In this regard, an organizational and technological decision was made on arrangement of an acceptance pit to perform cleaning operation (Fig. 4). Further, after completion of the work, a new well was built (Fig. 5).

Fig. 4. Sewage header in Severin Pototsky Street before restoration (RF5, Kharkiv, Ukraine, 2017)

Table 1

Main characteristics of the facilities where works for restoring conveyance capacity and cleaning the sewage headers were carried out (RF)

No.	Characteristic	Facility No.				
		RF1	RF 2	RF 3	RF 4	RF 5
Technical indicators						
1	Diameter, mm	600	700	700	800	700/900
2	Header material	steel	steel	reinforced concrete	reinforced concrete	bricks
3	Cross section shape	round	round	round	round	oval
4	Technical state	satisfactory				
5	Number of damages in the last 5 years, pc.	3	4	4	2	5
6	Scheduled TV inspection	yes	yes	yes	yes	yes
7	Damage nature*	A, C, F	B, C, F	D, E	D, E, F	E, F
8	Method of damage elimination**	b, c, e	a, b, d, e	d, e	d, e	a, e
9	Number of line connections to the header, pc.	3	3	4	2	1
10	Presence of turns in the header path	yes	no	yes	yes	yes
11	Path pitch	0.002	0.003	0.002	0.002	0.003
Organizational and technological indicators						
12	Cleaned section length, m	460	75	100	60	70
13	Foulness of the header passage area, %	50 %	30 %	25 %	35 %	60 %
14	Foulness nature	construction and household waste				
15	Number of target wells or pits for cleaning, pc.	9	2	3	2	3
16	Distance between the target pits, m	50, 60	75	40, 60	60	35, 35
17	Cleaning method	developed by the author	mechanical	hydrodynamic	hydrodynamic	developed by the author
18	Equipment parameters	depending on the cleaning section	power: 2,200 W	working pressure: 150 bar	working pressure: 160 bar	depending on the cleaning section
19	Working body	bucket	brush	nozzle/cutter	nozzle/cutter	bucket
20	Working body drive	rope	rods	rope	rope	rope
21	Need for liquid supply	yes/no	no	yes	yes	yes/no

*Notes: * – the damage nature: pitting (A); through corrosion (B); damage to the butt joint (C); damage to the header trough part (D); the header arch corrosion (E); the well wall corrosion (F); ** – method of damage elimination: local repair (a); applying steel coupling (b); sealing of the butt joint (c); partial replacement of the pipe (d); application of corrosion protection coating (e)*

Fig. 5. Restoring conveyance capacity of the sewage header in Severin Pototsky Street: after the restoration works (RF5, Kharkiv, Ukraine, 2017)

In addition to using the authors' method of cleaning sewage headers using the new bucket design, in restoration of conveyance capacity of sewage headers in Kharkiv (Table 1, RF2, RF3, RF4), conventional methods of cleaning, i. e. mechanical and hydrodynamic, were also used.

6. Discussion of results obtained in the study of using the method for cleaning the sewage headers

On the basis of generalized technical, organizational and technological characteristics of the networks, the most significant factors that affect efficiency of application of the method for cleaning sewage headers were determined. Symbols F1...F7 were assigned to the factors (Table 2).

Using the method of expert assessments, the factors were ranked in an order of increase or decrease of any inherent property [25]. When ranking, experts in the subject area arranged the factors influencing effectiveness of application of the method for cleaning sewage headers in an order that seemed to them the most rational and assigned ranks to these factors. The rank No. 1 was assigned the highest degree of significance of the factor influence on efficiency of the restoration work, and rank No. N was assigned the smallest degree. Therefore, the ordinal scale obtained as a result of ranking must satisfy the condition of equality of the number of ranks "7" to the number of ranked factors "n" [25]. Next, a summary table of ranks was compiled for all experts of the group (Table 3).

Table 2

The factors affecting effectiveness of application of the method for cleaning sewer headers

Item No.	Factor
F1	Diameter of the existing header
F2	Material of the worn header
F3	General technical state of the header (lining damage)
F4	Degree of foulness (percentage reduction of conveyance capacity)
F5	Foulness nature (silt, building waste, etc.)
F6	Profile of the restored section (presence of turns, the section length, a need for arrangement of additional pits or restoration wells)
F7	Conditions of work conduction (location and time)

Table 3

Results of polling the experts from the group

Factor	Expert							Sum
	1	2	3	4	5	6	7	
F1	5	4	6	6	4	3	5	33
F2	7	6	7	7	6	5	7	45
F3	4	5	5	4	5	6	4	33
F4	3	2	2	1	2	4	3	17
F5	1	1	3	2	1	1	2	11
F6	2	3	1	3	3	2	1	15
F7	6	7	4	5	7	7	6	43
Total	28	28	28	28	28	28	28	-

To determine consistency of experts, concordance coefficient W [26] calculated with the use of the following formula was applied:

$$W = \frac{7S}{m^2 \cdot \left(n^3 - n\right)}, \quad (1)$$

where m is the number of experts; n is the number of factors; S is deviation of the sum of the significance squares from the mean sum of the significance squares which is determined by the following formula [25]:

$$S = \sum_{i=1}^{n} \left(\sum_{j=1}^{m} R_{ij} \right)^2 - \frac{\left(\sum_{j=1}^{n} \sum_{j=1}^{m} R_{ij} \right)^2}{n}. \quad (2)$$

As a result of analysis of the table of standardized ranks and the conducted calculations, the concordance coefficient equal to 0.839 was obtained which indicates a high degree of consistency of opinions in the selected group of experts. The diagram of the total ranks of the factors under study based on the results of expert evaluation is shown in Fig. 6.

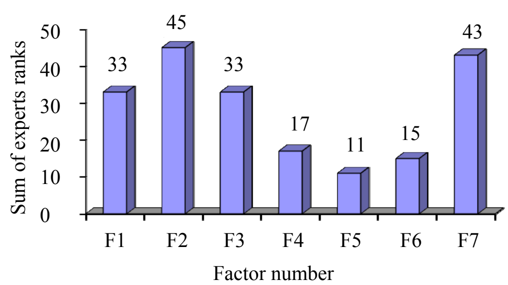

Fig. 6. Diagram of the total ranks of the factors under study according to the results of expert evaluation

From the data obtained, it should be noted that of the above-mentioned 7 factors, factors F4, F5, F6 (the total rank of these phenomena is minimal) have the highest degree of influence on effectiveness of the method for cleaning the sewage headers, namely:

– degree of foulness (percentage reduction of the header conveyance capacity);

– nature of foulness (silt, construction debris, etc.);

– profile of the restored site (presence of turns, length of the site, the need for additional pits or recovery wells).

The above factors directly affect technical and economic indicators (TEI) of the work: cost price, labor-intensiveness, and duration of recovery of the header conveyance capacity. This is determined by the fact that the set of parameters can change TEI in various dynamics through the cleaning work stages. So, for example, the degree and nature of foulness may differ depending on the section of the recovered header which will affect labor intensity and duration of work, and as a consequence, the cost price. In view of this, only a comprehensive assessment of all factors influencing conduction of the restoration work can show expediency of application of the cleaning method with the new bucket design proposed by the authors.

Table 4 presents technical and economic indicators of the facilities at which restoration of conveyance capacity and cleaning of the sewage headers in the city of Kharkiv was carried out by various methods.

It should be noted that duration of the work includes preparatory and main periods. The main period of work includes cleaning of the header as well as arrangement of new wells. The cost of works depends on the conditions of their conduction, diameter of the existing header, the degree of its foulness and the nature of sediments. Using the example of operating organizations in Kharkiv, it can be observed that the use of traditional methods for cleaning the sewage headers (hydrodynamic and mechanical) is inferior to the technical and economic indicators proposed by the authors of the alternative method for cleaning the headers using the new bucket design. This is due, first of all, to the high cost of imported equipment for hydrodynamic and mechanical cleaning.

Efficiency of cleaning the headers by these methods and restoring conveyance capacity of the pipeline is 100 %. In turn, a significant disadvantage of using these methods is the high cost of equipment and restoration work.

Comparison of the existing methods of cleaning the sewage headers and the results obtained using the proposed method, makes it possible to draw the following conclusions:

– the proposed method combines positive aspects of the existing ones and can work both purely mechanically and with the addition of hydraulics;

– it can be used for cleaning the headers of various diameters and structure types;

– it allows one to reduce duration and energy costs of cleaning operations.

The limitations of the study can be attributed to the fact that the method was tested for large diameter headers, their cross-section, and the path profile. However, they do not significantly affect quality of work. It was confirmed by the method of expert assessments. In the future, studies should be carried out to widen capabilities of this method, that is, test it in conditions of influence of advanced indicators of performance efficiency factors.

Table 4

Technical and economic indicators of the facilities at which restoration of the conveyance capacity and cleaning of the sewage headers was carried out (RF)

Item No.	Characteristics	Facility No.				
		RF1	RF2	RF3	RF4	RF5
1	Length of the section, m	460	75	100	60	70
2	Duration of performing the works at RF, day	90	8	8	12	30
3	Duration of performing the works for restoring conveyance capacity per 10 m of the header, day	1.95	1.06	0.9	2	0.64
4	Cost of cleaning 1 m of the header, USD	430	1,550	1,800	1950	500

7. Conclusions

1. A new method was proposed for cleaning the sewage headers using a bucket which is intended for networks with pipe diameter more than 400 mm and in the presence of not only silt but also stony sediments. When using this method, it is possible to perform work both purely mechanically and with additional feed of pressurized liquid.

2. The sewage headers were cleaned according to the proposed method with a bucket of a combined cleaning at five facilities in Kharkiv, Ukraine, which differ in diameter, type of header material and type of fouling.

3. The results of study of the factors affecting efficiency of cleaning the sewage headers using the new cleaning method and bucket have shown that the greatest impact on work execution is exerted by the degree of foulness and its nature as well as the profile of the restored path. Due to the combined method, the headers are cleaned with one and the same equipment without replacement and additional installation of new equipment which makes it possible to reduce costs for various indicators.

4. The results of using the proposed method for cleaning the sewage headers confirm its feasibility as it ensures decrease in repair work duration as well as lower resource and energy costs. Accordingly, by its technical and economic indicators, the proposed method for cleaning the sewer headers is advanced since its application can eliminate 75–85 % of the total foulness. This figure is permissible according to the requirements to operation of headers.

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