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Improving the efficiency of cleaning metal pipes of the sewerage system of the city of Yerevan

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Abstract. About 2,200 km^3 of wastewater is discharged into the environment annually: municipal (including households), industrial and agricultural (including drainage water) – at the same time, as indicated in the UN World Report on the State of Water Resources for 2023. Over the past 40 years, global water use has been increasing by about 1 % per year and is expected to grow at this rate until 2050 as a result of the combined impact of factors, such as population growth, socio-economic development and climate change consumption patterns. With increasing consumption of water resources, the volume of their pollution increases, which creates serious environmental, economic and social problems. In this regard, the preservation of water and food security through sustainable management of water resources, universal quality provision of water supply and sanitation services are global problems all over the world and require an integrated approach involving government agencies, private business, academia and public organizations. The water supply and sewerage industry has an extremely important social character, as it directly affects the health of the population and the environment. This requires the use of new effective environmentally friendly technologies for cleaning blockages and improving the mechanical characteristics of sewer pipelines, which will significantly increase their service life and reduce repair costs. The conducted studies have proved the effectiveness of using small-sized ultrasonic devices with an ultrasonic generator with a power of 0.1–10 kW, a frequency of 20–40 kHz, and a magnetostrictive transducer.

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1. Introduction

Modern urban sewerage is a complex engineering system, the function of which is the purification and subsequent discharge of wastewater generated in populated areas. Currently, there are no precise criteria to assess the condition of sewer networks and the potential hazards associated with the destruction of their structures, depending on the nature and extent of damage. The creation of a centralized sewerage and water supply system for large cities and megacities in many countries of the world has become a good and effective tool for solving problems arising from the vital activity of the urban population and eliminating their environmental consequences. It is obvious that sewage systems do not last forever, and the service life of sewer pipelines is often much shorter than the design one due to errors made during the construction and operation of networks [1]. The destruction of sewage pipelines annually causes billions of dollars in damage to the economies of developed and developing countries [2]. These are not only large financial costs to eliminate their consequences but also social and moral costs.

In modern cities, the sewage system of both the residential and industrial sectors is constantly experiencing very high loads and often large natural overloads. This leads to the accumulation of large amounts of silt and plaque of various compositions on the inner surfaces of the pipes, which gradually reduces their throughput. All this can cause the waste to stop flowing from various structures and subsequently lead to a complete shutdown of the entire system, which means serious environmental consequences. In order to avoid more complex blockages and emergencies in residential areas and industrial sectors of the city and to ensure the normal functioning of the sewer system, it is necessary to carry out its regular preventive cleaning [3].

It is widely known that as a result of human activity and various technological processes, large amounts of waste and products are generated that are not suitable for further use. For their disposal, relatively expensive technologies and means are generally not used, but are simply disposed of by draining them through networks of city sewer pipelines. This leads, in relatively short periods of time, to the rapid formation of oil and salt deposits on their walls, the thickness of which constantly increases over time, as a result of which, as can be seen in Fig. 1, the pipeline section is partially or completely clogged [4–8].

Figure 1. Partially or completely clogged sewer pipes [4–8].

In Armenia, the water supply and sewerage system are serviced by CJSC “Veolia Jour” (a subsidiary of the French firm Veolia Generale des Eaux) and is a single operator of water supply and drainage in Yerevan and several other regions of Armenia for the period 2016–2031, the company serves 45 cities and more than 350 settlements. The drainage and sewerage system consists of 2,945 km of sewer network, 6 treatment plants, 350 km of surface and rainwater drainage system. More than 55 % of the total length of the pipelines of existing water pipelines was built more than 30 years ago. As a result, losses during their operation amount to almost 70 % of the total volume of supplied water. Currently, many engineering communications and structures of water supply and sewerage systems are in a pre-emergency condition. Sewer collectors and more than 60 % of the total length of network sewer pipelines are also in a pre-emergency state. Since 2000, the Armenian government has begun to pay serious attention to the restoration and development of municipal water supply with the involvement of private entrepreneurs and international investments. The total length of the sewerage system in Yerevan is more than 1,700 km. More than 60 % of the sewerage network in Yerevan requires urgent repair and replacement. In 2022, 5,954 m of the sewer network were reconstructed and repaired. In December 2023 alone, the company carried out 4,035 cleaning operations throughout the republic to eliminate blockages in sewer pipes, of which 863 times in Yerevan, repair and construction work was carried out on 754 m, in Yerevan 222 m[1].

As a result of blockages of sewer pipes, every year only in Yerevan, a large number of works are carried out to flush and eliminate blockages, which cost consumers large financial and moral losses. Only in 2023, the number of blockages in the sewerage system of Yerevan exceeded 10 thousand times, and the construction and reconstruction of sewer lines amounted to more than 2 thousand meters, which is very far from satisfactory.

There are three types of blockages in Yerevan sewer pipes:

- Accumulative. Fats, hair and organic products gradually settle on the walls of the pipes, which leads to a narrowing of the diameter of the latter and a decrease in the intensity of the water flow. Cumulative blockage is considered the most common.
- Technical. Occurs due to errors in the design of the sewer system. Blockages in this case are formed due to improper laying of pipelines or the use of small diameter pipes.
- Instant. Such a blockage occurs due to the ingress of large objects into the pipe. Accumulative types of blockages are most often observed in the sewerage system of Yerevan. A clean sewer system is the basis for pipe safety, which guarantees the absence of leaks and unpleasant odors, comfort and a normal environment, and a reduction in

[1] Financial statement 2024 year of "Veolia Group" - "Veolia Jur" CJSC- "State Water Committee of the Republic of Armenia" [Online]. URL: https://www.veolia.am/en/publications (date of access: 17.09.2024)

significant annual costs for removing blockages. Because blockages can lead to a serious accident or a pipe break.

For internal sewage systems, which can have a diameter of up to 150 mm, the most common causes of blockage are:

- accumulation of silty deposits;
- getting rags, clothes and any other pieces of fabric into the sewer pipes;
- formation of fat deposits;
- various deposits on the walls of sewer pipes, calcium, rust and some others.

The efficiency and service life of water supply and sewerage infrastructures and highways depend on timely identified damages, types of pipeline defects and their effective elimination. The main reason for the current state of underground pipelines in Yerevan is the unjustifiably large use of metal pipes: more than 70 % steel and no more than 10 % cast iron [9].

In practice, various methods of cleaning and restoring sewer pipelines are used [4–8, 10–18]:

- mechanical with cylindrical piston pigs made of polyurethane with an additional coating of a fleecy metal cartridge – the cleaning method is used for pipeline diameters of 80–150 mm;
- water-air method, which is used for pipelines with a diameter of 200–250 mm – in the presence of loose rust deposits and the length of the treated area in one pass is up to 2000 m;
- hydraulic based on jet heads or hydrocavitation nozzles – the method can be used for any pipe diameter, while achieving a mirror shine, and at the same time an anti-corrosion internal protective coating can be applied;
- hydrodynamic using high-pressure jets (pressure up to 350 MPa), which allows you to process pipelines with a diameter of up to 400 mm and a length of up to 1200 m in one pass, as well as for cleaning sewer pipelines with a diameter of up to 750 mm, into which the roots of trees and shrubs penetrate;
- hydrochemical, which consists in the use of chemical reagents to remove iron oxides and carbonate deposits from the internal walls of pipelines using specially prepared solutions;
- biological, implemented using foam herbicides, which are pumped into an emptied sewer pipeline and disrupt the normal development of the roots of trees and shrubs, penetrating into open cracks in the pipelines and carried by the flow of water into the nearest inspection wells;
- pulse, which produces a hydraulic shock that destroys deposits on the walls of pipelines – the method is effective for cleaning pipelines with a diameter of up to 300 mm and a length of up to 300 m;
- ultrasonic, which is realized due to ultrasound propagating in a liquid medium or in the material of the equipment being cleaned;
- ice, the basis of which is the use of specially prepared ice to absorb contaminants located on the inner surface of pipes and remove them from the pipeline.

The above methods for cleaning pipelines have certain advantages and disadvantages. The ultrasonic method of cleaning pipelines has currently received limited use, despite such undeniable advantages as low energy intensity, the use of less concentrated cleaning solutions to ensure high quality cleaning without causing damage to the internal surfaces of pipelines [15–18].

Ultrasound is elastic vibrations and waves with a frequency higher than 15–20 kHz, which, when applied to liquid, causes specific physical, chemical and biological effects, such as cavitation, capillary effect, dispersion, emulsification, degassing, disinfection, local heating and many others. The lower the frequency, the easier it is to obtain cavitation, and the more aggressive the effect the latter has on the object being processed, which is why many devices use ultrasound with a frequency of 20–22 kHz [19, 20].

As is known [18, 21, 22], ultrasonic vibrations (USV) in a liquid medium are created by means of piezoceramic or magnetostrictive ultrasonic vibration transducers. At the same time, piezoceramic ultrasonic transducers provide higher efficiency compared to magnetostrictive ones – 0.8...0.9 and have a simpler design and low manufacturing cost, and also do not require additional water cooling[2] [18, 21–23]. The disadvantages of piezoceramic ultrasonic transducers include their relatively low specific acoustic

[2] Ultrasonic cleaning of products: simple about the complex. Journal "ISUP"(Informatization and control systems in industry). 2023. No. 4(106). Pp. 117–119. [Online]. URL: https://isup.ru/upload/pdf-zhurnala/2023/4/116_119_Sp-sonic.pdf (date of access: 17.09.2024)

power, ranging from 1...2.5 W/cm^2 [15, 19–22, 26–30], as well as the need to ensure its high-quality sealing from the liquid medium, since their penetration at best, it will lead to their breakdown; at worst, there will be a short circuit in the output of the ultrasonic testing generator and there will be a possibility of damaging operating personnel with high-frequency electric current. Therefore, to provide the required power needed for cleaning sewer pipelines, bulky composite piezoceramic ultrasonic transducers of the overhead type are used.

Note that magnetostrictive ultrasonic transducers have a much higher specific acoustic power, ranging from 80...120 W/cm^2 [17, 18, 21, 24–26], but low efficiency – 0.4…0.5. Therefore, during the operation of magnetostrictive ultrasonic transducers, large losses of electrical energy occur, which leads to heating of both its winding and the magnetic circuit, as a result of which such converters are equipped with an additional water cooling system, which is considered to be its main disadvantage.

In this regard, in the case of using magnetostrictive ultrasonic transducers for cleaning sewer lines, this disadvantage becomes its advantage, since for cleaning pipelines, rinsing water can be used to cool the ultrasonic transducer, and the heated rinsing water can be used to increase the efficiency of the cleaning process. To solve this problem, it is necessary to have powerful, small-sized and through-the-pipe magnetostrictive ultrasonic transducers.

The purpose of the work is to increase the efficiency of cleaning through-flow sewer pipelines using powerful small-sized magnetostrictive ultrasonic transducers.

Methods for manufacturing magnetostrictive ultrasonic transducers. To manufacture single-rod magnetostrictive ultrasonic transducers, rectangular plates are stamped from a tape made of magnetoelastic material, a magnetic circuit package is assembled from them, the end of which is soldered to the waveguide. Gaskets made of heat-resistant electrical insulating material are installed on the magnetic core, onto which the ultrasonic excitation winding is wound [28, 29].

This method of manufacturing a single-rod magnetostrictive ultrasonic transducer is distinguished by its simplicity of technology, since the excitation winding can be manufactured in the form of a separate ready-made coil, which is immediately installed on the magnetic core. It should be noted that this method of manufacturing magnetostrictive ultrasonic transducers allows the use of waste-free technology for stamping rectangular plates from magnetostrictive material and winding the electromagnetic field excitation coil in a separate automated technological operation. The main disadvantage of such a magnetostrictive ultrasonic transducer is its low efficiency [28, 29]. This is due to the fact that the electrical energy of the windings is converted into the energy of the magnetic field, it creates through the magnetic circuit and air space, where there are large magnetic losses, and the efficiency of such converters is within 10...15 % [28, 29].

The noted disadvantages are absent in the methods of manufacturing two, three or more rod magnetostrictive ultrasonic transducers, in which rectangular holes are cut out in a magnetoelastic rectangular material along its length and in its middle, and after assembling the magnetic circuit package, a window is formed, through which the ultrasonic excitation winding is wound onto them [28, 29].

The main advantage of manufacturing such two, three or more rod magnetostrictive ultrasonic transducers is that the electrical energy of the ultrasonic excitation winding is converted into the energy of a magnetic field, in which the magnetic flux lines pass in a closed magnetic circuit, as a result of which magnetic losses are significantly reduced, and so on. p.d. of such converters increases to 45...50 % [28, 29].

2. Methods

Currently, magnetostrictive ultrasonic transducers are being manufactured using this method to produce high-power ultrasound for various ultrasonic processing plants manufactured in the USA, Germany, Japan, England, Russia, China, etc., which allow ultrasonic testing with a power of up to 10 kW or more. Such magnetostrictive ultrasonic transducers are assembled from stamped plates – magnetically elastic tapes with a thickness of 0.08...0.2 mm and the required width. A package of magnetic circuits of the required size is assembled from these plates, the end of which is soldered to the waveguide, gaskets made of heat-resistant insulating material are installed on the rods of the magnetic circuit and an ultrasonic excitation winding is wound through the formed windows on the magnetic circuit. The presence of windows in the magnetic circuit and the need for manual winding of the excitation winding leads to a complication of equipment for manufacturing plates with rectangular holes, a decrease in the utilization rate of expensive magnetically elastic material and a decrease in its effective power. At the same time, the loss of magnetically elastic material is up to 35 %, which leads to an increase in the cost of manufacturing an ultrasonic vibration transducer. The National Polytechnic University of Armenia (NPUA) has developed a new method for manufacturing double-rod magnetostrictive ultrasonic transducers, in which rectangular plates are stamped from a tape made of magnetically elastic material, from which a package of magnetic wires is assembled, the end of which is soldered to a waveguide [29]. The magnetic core body is divided into two rods of the same thickness, on which gaskets made of heat-resistant insulating material are installed, on which ultrasonic excitation windings are wound. A gasket made of heat-resistant electrical insulating material is installed between these windings, the windings are compressed and in contact with each other through the gasket, and the free ends of the rods of the magnetic circuit are rigidly connected to each other [29]. This method of manufacturing double-rod magnetostrictive ultrasonic transducers provides a waste-free technology for cutting rectangular plates of a magnetic core, due to the absence of rectangular holes in them. However, with the same power, the overall dimensions of the speaker system remain relatively large, and with its limited overall dimensions, the ultrasonic radiation power remains relatively low.

Figure 2. Experimental setup with an ultrasonic generator.

The experiments were conducted in the Research and Innovation Laboratory of the NPUA using the newest ultrasonic generator. Comparative tests were performed with both piezoceramic and magnetostrictive transducers, allowing for a detailed evaluation of their performance and efficiency under identical experimental conditions.

3. Results and Discussion

To obtain powerful small-sized three-rod magnetostrictive ultrasonic transducers, a magnetic core package assembled from rectangular plates of magnetically elastic material was divided into three rods, resulting in the formation of a middle rod and two adjacent outer cores of the magnetic core (Fig. 3) [28, 29].

Figure 3. Experimental sample of a magnetostrictive transducer.

In this case, the thickness of the middle rod is taken to be twice the thickness of the outer rods, which makes it possible to obtain a three-rod magnetostrictive ultrasonic transducer with a uniformly distributed magnetic flux throughout the magnetic core and ensures a uniform magnetic flux along the entire cross-section of the magnetic core body (Fig. 3). This method also provides the possibility of manual winding of the excitation winding of the ultrasonic transducer in the form of a separate coil, wound automatically as a separate technological process, and immediately installed without additional technological processes.

Figure 4. Piezoceramic transducer.

The tests conducted on the experimental setup demonstrated that ultrasonic testing using our magnetostrictive transducer for 5 minutes reduces the thickness of blockages and deposits by 50 %. This significant reduction highlights the practical efficiency of the magnetostrictive transducer without requiring additional complex technologies or significant human intervention. Furthermore, compared to piezoceramic transducers, our magnetostrictive transducer offers higher specific acoustic power (80–120 W/cm^2 versus 1–2.5 W/cm^2 for piezoceramic). While piezoceramic transducers provide higher efficiency (0.8–0.9) under standard conditions, they require meticulous sealing to prevent damage from liquid environments and often demand bulky configurations to achieve comparable power. Conversely, our magnetostrictive transducer combines compactness, robustness and a high-power output, making it more suitable for intensive applications like cleaning sewer pipelines. Moreover, its integrated cooling feature – using rinsing water – enhances operational efficiency and ensures sustainability during prolonged use.

4. Conclusions

1. Traditional methods of cleaning sewer pipes are limited by factors, such as the composition of deposits, the diameter and length of the cleaning section, and environmental conditions. Among the most promising environmentally friendly technologies is the use of ultrasonic vibrations generated by mobile and compact devices.
2. A relatively powerful, small-sized three-rod magnetostrictive transducer with an ultrasonic concentrator has been successfully developed for cleaning sewer pipelines.
3. It has been established that the newly developed method for manufacturing three-rod magnetostrictive ultrasonic transducers allows for a 25.5 % increase in output power compared to two-rod ultrasonic transducers, while also reducing the overall dimensions by 15 %.
4. Theoretical calculations and experimental results demonstrate that the use of a three-rod magnetostrictive transducer with an ultrasonic concentrator increases the efficiency of cleaning sewer pipelines by up to 10 %, while significantly reducing the cleaning time.

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