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ESTIMATION OF ELECTRICITY CONSUMPTION FOR WATER TRANSPORTATION IN PRESSURE PIPELINES AFTER THEIR REPAIR

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Abstract. The issues of using pipes made of different materials in water supply systems and the current situation with the technical condition of pressure pipeline transport are considered. It is noted that in order to ensure the standard service life of pipelines, it is necessary to carry out high-quality repair and restoration work using trenchless technologies and modern building materials, which include polymer pipes and flexible hoses. The object of research is a section of a dilapidated steel pipeline network of a certain thickness, diameter, depth and groundwater level above the tray. For the renovation of the pipeline, internal protective coatings are used, applied by dragging new pre-compressed polymer pipes and flexible polymer sleeves based on fiberglass. A description of trenchless technologies is presented, as well as automated programs that implement the tasks of determining the technological parameters (wall thickness of a polymer pipe and a polymer sleeve), hydraulic calculation of pressure losses depending on the degree of roughness of the pipeline walls, the inner diameter of a new two-layer pipe structure when passing a certain water flow, as well as the amount of electricity consumed for water transportation when appropriate wall thicknesses of protective coatings.

Keywords: pipelines, reconstruction, protective coatings, energy consumption

ОЦЕНКА ПОТРЕБЛЕНИЯ ЭЛЕКТРОЭНЕРГИИ НА ТРАНСПОРТИРОВКУ ВОДЫ В НАПОРНЫХ ТРУБОПРОВОДАХ ПОСЛЕ ИХ РЕМОНТА

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Аннотация. Рассмотрены вопросы использования в системах водоснабжения труб из разных материалов и сложившуюся ситуацию с техническим состоянием напорного трубопроводного транспорта. Отмечено, что для обеспечения нормативного срока службы трубопроводов необходимо качественное проведение ремонтно-восстановительных работ с использованием бестраншейных технологий и современных строительных материалов, к которым относятся полимерные трубы и гибкие рукава. Объектом исследований является участок ветхой трубопроводной сети из стали определенной дины, диаметра, глубины залегания и уровня грунтовых вод над лотком. Для реновации трубопровода используются внутренние защитные покрытия, наносимые путем протаскивания в трубопровод новых предварительно сжатых полимерных труб и гибких полимерных рукавов на основе стекловолокна. Представлено описание бестраншейных технологий, а также автоматизированных программ, реализующих поставленные задачи определения технологических параметров санации (толщины стенки полимерной трубы и полимерного рукава), гидравлического расчета потерь напора в зависимости от степени шероховатости стенок трубопровода, внутреннего диаметра новой двухслойной трубной конструкции при пропуске определенного расхода воды, а также величины затрачиваемой электроэнергии на транспортировку воды при соответствующих вариантах толщины стенок защитных покрытий.

Ключевые слова: трубопроводы, реконструкция, защитные покрытия, энергозатраты

INTRODUCTION

In cities and towns of Russia, steel and cast-iron pipelines have become the most widespread in pressure pipeline transport systems [1]. However, over the past 30 years, both in Russia and abroad, polymer pipes have become a serious competitor to steel, cast iron and reinforced concrete pipes [2]. In particular, in the Russian Federation, they account for 86.5% of newly built water supply networks after 2010, excluding data for Moscow and St. Petersburg. In addition, polymer pipes and flexible hoses made of polymer materials have firmly become one of the most promising building materials for the renovation of pipelines made of various materials [3]. Despite the clear progress in terms of the widespread use of pipes made of such traditional materials as steel, cast iron and others for both construction and trenchless repair of pipelines, their actual service life is below the standard values. Statistics show that, in general, in all settlements of the Russian Federation, there is an excess of the standard service life of water supply networks up to 40.8%. This circumstance is a consequence of the early appearance of various kinds of defects and, as a result, an increase in the amount of leaks of transported water [4, 5]. At the same time, it should be noted that the pace of renovation of existing domestic pipeline water supply networks, where modern trenchless technologies are used, sometimes leaves much to be desired, since they amount to about 2 and at best 4% per year of the length of the networks with a need of about 7-8%, which would allow in the coming years to fully restore the required condition and efficient operation pipeline networks [6]. To ensure the standard service life of pipelines, it is necessary to carry out high-quality repair and restoration work using modern materials, which include polymer pipes and hoses. An equally important component of the task of effective reconstruction of pressure pipeline transport is the reduction of energy costs for transporting water through a two-layer pipeline after construction work [7-9].

Foreign researchers note that a significant role in energy consumption in water distribution systems is given to their hydraulic indicators and the effective management of hydrophore stations (i.e. pumping stations with several parallel installed pumps), when modeling (by correlation) between the amount of water supplied and electricity is necessary [10, 11].

Also, a certain role in energy consumption is given to the temperature factor, in particular, the temperature of the surrounding natural environment (i.e., the soil where the pipeline is laid and transported water) [12], as well as increasing the capacity of the restored pipeline network based on the changing parameters of its operation [13-15].

The circumstances listed above are a significant argument when making the final decision on choosing the appropriate trenchless renovation method, since operating costs for electricity can affect the payback period of restoration work [16].

The essence of the method of stretching a new polymer pipeline into an old one is that the outer diameter of the polymer pipe slightly exceeds the inner diameter of the steel pipeline being restored. Due to the preheating of the polymer pipeline in a special installation and subsequent compression in a conical matrix, its diameter decreases and the walls thicken at the same time. After cooling for several hours, the polymer pipeline increases in diameter to values equal to the inner diameter of the old pipeline, i.e. it fits snugly in the inner surface, forming a two-layer pipe structure [17, 18].

In turn, the essence of the method of applying a flexible polymer sleeve based on fiberglass consists in its inversion in an old pipeline (steam or water pressure) and subsequent polymerization of organic resin previously applied to the inner surface of the sleeve billet, forming a durable two-layer pipe structure [19].

Figure 1 shows an illustration of the process of heating, compressing and dragging a polymer pipeline into an old one, and Figure 2 shows as a sample one of the possible schemes for applying a flexible polymer sleeve using an inversion drum.

METHODS AND MATERIALS

The study consists of two stages, where, at the first stage, the analysis of design options for restoration work on a dilapidated steel pipeline is carried out using the technology of stretching pre-compressed polymer pipes into it, and at the second stage flexible polymer hoses are considered as the object of research. Polymer pipes with different SDR values (the ratio of diameter to wall thickness of the pipe), as well as different wall thicknesses of polymer hoses, depending on their modulus of elasticity and a number of conditions for laying the old pipeline (diameter, length, depth and groundwater level), are subject to analysis for the most effective use in terms of saving electricity during water transportation. The research method is the analysis of automated calculations to determine the complex parameters of a polymer pipeline after operations for its compression and straightening in an old pipeline, taking into account the transformation of hydraulic and energy parameters of a two-layer pipeline structure [20, 21].

Automated programs were used as information retrieval systems [22-24].

The initial information for carrying out the entire complex of necessary technological, hydraulic and energy calculations using the above-mentioned automated programs is the following:

-the inner diameter of the old steel pipeline to be renovated d: 400 mm (outer 426 mm);
-length of the pipeline l: 4500 m;
-depth of the pipeline H: 3.0 m;
-groundwater level h: 2.5 m of water column;
-flow rate of transported water Q: 0.134 m3/s;
-efficiency of the pumping unit ηp: 0.9;
-outer diameter of the polymer pipe dp: 450 mm;.

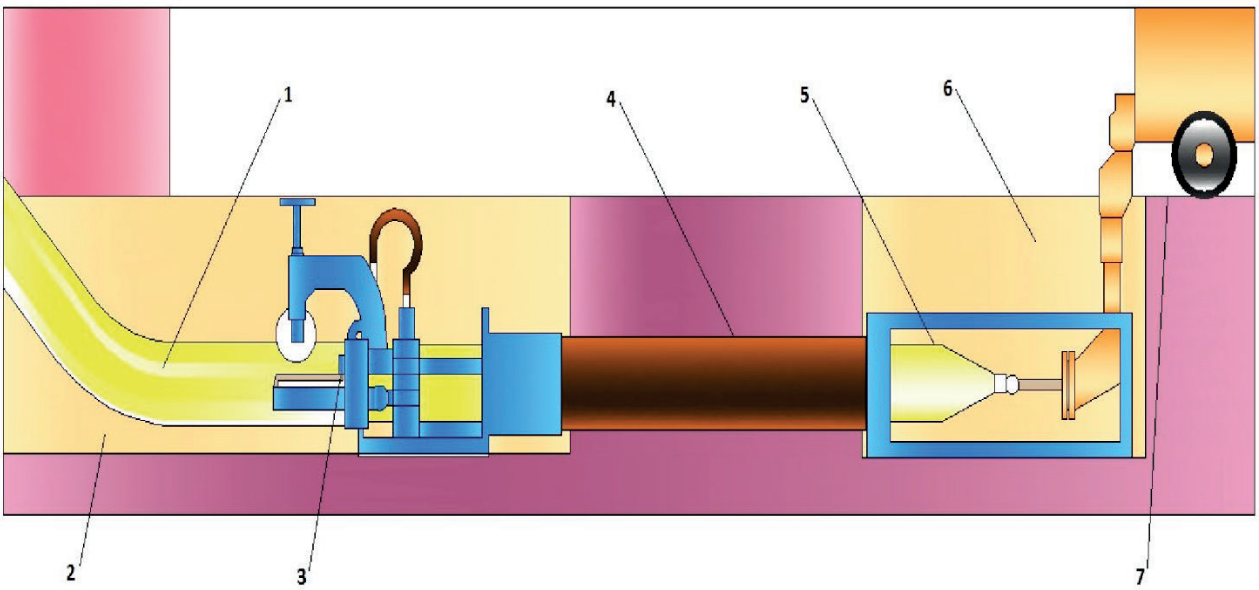

Figure 1. An illustration of the operations of preheating, compressing and dragging a polymer pipe into an old pipeline
1-polymer pipe subject to thermomechanical compression, 2- starting well, 3- device for stretching a pipeline with a furnace chamber and a narrowing matrix, 4- section of the pipeline being restored, 5- deformed polymer pipeline, 6- finishing well, 7- site for installing equipment for the implementation of the process

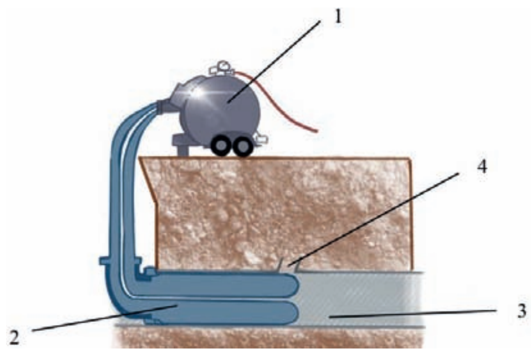

Figure 2. Inversion of a flexible polymer sleeve using a special drum
1- inversion drum; 2- polymer sleeve; 3- repair site; 4- pipeline defect

RESULTS

The calculation of energy consumption savings during water transportation through a pipeline for two alternative repair options is performed according to formulas (1) and (2), which are basic in the algorithms of the above-mentioned automated programs [25].

$$\Delta E_{1m}=[9.81\cdot Q^3(A_s - A_n)\cdot 24\cdot 365]/\eta_p \qquad (1)$$

where Δ E is the amount of savings in electricity consumed, kW·h/year; Q is the consumption of transported water, m^3/s; A_s and A_p are, accordingly, the resistivity coefficients of the old and restored pipeline using the technology of dragging a polymer pipe or a flexible polymer sleeve; η_p is the efficiency of the pumping unit; *l* is the length of the pipeline, *m*; 24 is the number of hours of pump operation per day, *h*; 365 –the number of days in a year

$$A_s = 0{,}0017 d_s^{-5{,}1359} \qquad (2)$$

where d_s is the inner diameter of the old pipeline, *m*; d_n is the inner diameter of the new two–layer pipeline structure, *m*

For the reconstruction option of the old pipeline using a polymer pipe with a wide range of *SDR* values, the resistivity coefficients of the A_n are calculated using the formula (3), and for a polymer sleeve A_n based on fiberglass for the base array of the considered values of the elastic modulus *S* (N/mm^2) according to the formula (4):

$$A_n = 0{,}0004 d_n^{-5{,}7276} \qquad (3)$$

$$A_n = 0{,}0007 d_n^{-5{,}2791} \qquad (4)$$

The above formulas for the dependence of resistivity on the diameter *An=f(d)* were obtained experimentally on experimental hydraulic stands in the laboratory of the National Research University MGSU, where pipes made of various materials [17].

The results of the automated calculation of technological, hydraulic and energy parameters in the implementation of renovation technology by dragging a polyethylene pipe into an old pipeline are presented in Table 1.

Table 1. Summary data of the automated calculation when using a polymer pipe with an outer diameter of 450 mm for renovation

Calculated values for different SDR	SDR 17	SDR 21	SDR 26	SDR 33	SDR 41	SDR 50
The wall thickness of the polymer pipe after compression and straightening operations in the old pipeline, mm	27.09	21.64	17.5	13.95	11.09	9.04
The inner diameter of the double-layer pipeline after renovation, mm	345.81	356.71	365.0	372.11	377.81	381.91
Pressure losses along the entire length of the pipeline before renovation, m of water column	15.698					

Pressure losses along the entire length of the pipeline after renovation, m of water column	14.152	11.847	10.386	9.301	8.524	8.041
Average annual energy savings after renovation, kW·h/year	21987.7	54749.4	75521.1	9955.4	101992.0	109250.0

According to Table 1, with an increase in the SDR values, there is a pronounced tendency to change the inner diameter of a two-layer pipe structure due to a decrease in the wall thickness of the polymer pipe. Also, with an increase in SDR, there is a significant reduction in pressure losses along the entire length of the pipeline. At the same time, the average annual energy savings increases with an increase in SDR due to an increase in the diameter of the two-layer pipe structure after renovation. The observed effect in terms of energy savings is also achieved due to the lower hydraulic resistances of the polymer pipe compared to steel.

For the case of use during the renovation of a polymer sleeve, calculated data on wall thicknesses, elastic modulus values and internal diameters of a two-layer pipe structure are presented in Table 2.

Table 2. Summary data of the automated calculation when using a polymer sleeve for renovation

The values of the elastic modulus S, N/mm2	3500	4000	4500	5000	5500	6000	7000	8000
The thickness of the polymer sleeve in the old pipeline, mm	4.8	4.7	4.5	4.4	4.3	4.2	4.1	4.0
The inner diameter of the double-layer pipeline after renovation, mm	390.4	390.6	391.0	391.2	391.4	391.6	391.8	392.0
Average annual energy savings after renovation, kW·h/year	90578.4	90919.1	91476.7	91754.2	92013.7	92306.5	92581.3	92855.2

According to Table 2, the thickness of the polymer sleeve at elastic modulus values in a wide range (3500-8000 N/mm2) does not undergo significant changes, which practically does not affect the amount of annual energy savings calculated by formula (1).

Comparing the calculated data presented in tables (1) and (2), it can be stated that the most advantageous reconstruction option in terms of saving electricity during water transportation is the use of trenchless technology of pre-compression of a polymer pipe and its dragging into an old pipeline in the SDR values 33-50 range. However, in the range of SDR values 17-26, the polymer pipe as a protective coating is significantly inferior to the polymer sleeve in terms of achieving an energy-saving effect.

In order to analyze the possible expansion of the effective range of SDR values of polymer pipes during the renovation period, an automated calculation was performed, provided that a polyethylene pipe with a smaller outer diameter, i.e. 400 mm instead of 450 mm, is used to drag into the old pipeline. The calculation results are presented in Table 3.

Table 3. Summary data of the automated calculation when using a polymer pipe with an outer diameter of 400 mm for renovation

Calculated values for different SDR	SDR 17	SDR 21	SDR 26	SDR 33	SDR 41	SDR 50
The wall thickness of the polymer pipe after compression and straightening operations in the old pipeline, mm	23.7	19.0	15.4	12.3	9.8	8.0

The inner diameter of the double-layer pipeline after renovation, mm	352.6	362.0	369.2	375.4	380.4	384.0
Pressure losses along the entire length of the pipeline before renovation, m of water column	15.698					
Pressure losses along the entire length of the pipeline after renovation, m of water column	12.661	10.89	9.728	8.843	8.198	7.767
Average annual energy savings after renovation, kW·h/year	43182.4	63361.6	84876.0	97458.3	106633.7	112754.6

An analysis of the data in Table 3 shows that in this case, there is also an advantage of the steel pipeline repair method by dragging a polymer pipe compared to a polymer sleeve in the same SDR ranges, i.e. 33-50. However, the average annual energy savings when replacing a pipe with a smaller outer diameter increases, for example, for SDR 50 by 3.21% (112754.6×100/109250).

Thus, it can be stated that when choosing the technology of trenchless reconstruction of dilapidated pressure pipelines, the required standard standards in terms of their strength can also include the amount of energy saving, characterizing it as an additional significant argument for making a final decision. Using automated calculations, it is possible to identify the most effective use case for a particular technology for the appropriate renovation of old pipelines of certain diameters and lengths, depths of occurrence, costs of transported water and other parameters. Such a methodological approach using automated information retrieval systems for estimating electricity consumption, as well as carrying out estimated calculations of the cost of repair and restoration work, make it possible to choose the optimal option for trenchless renovation of pressure pipelines, taking into account their initial technological parameters and the nature of defects.

CONCLUSIONS

1. An analysis of the use of alternative trenchless technologies for the renovation of dilapidated pressure pipelines, including accompanying algorithms and automated programs for calculating technological, hydraulic and energy parameters, is presented.
2. A methodological approach to the automated selection of the optimal option for the renovation of old pipelines with polymer pipes and flexible polymer sleeves is recommended and implemented, which allows us to identify a range of wall thicknesses of protective coatings of pipelines and their diameters, which save energy costs for water transportation.

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