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ANALYSIS OF THE ROUGHNESS PARAMETERS AND CHEMICAL COMPOSITION TRANSFORMATION OF THE PROTECTIVE COATING OF A PIPELINE DURING ITS REPAIR

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Abstract. The issues of potential transformation of the surface roughness of solid samples of the sprayed protective coating Subcote FLP, used during the period of trenchless reconstruction of pressure pipelines, are considered. The technique of conducting experiments on the dynamics of changes in the roughness of samples in the time range by immersing them in a container with water, dosing a disinfectant into it and processing water on a magnetic stirrer with subsequent analysis of the surface of samples by methods of lightoscopy and profilometry are presented. Changes in the qualitative characteristics of coating samples and chemical indicators of water are identified and analyzed. The dynamics of changes in the equivalent roughness coefficient of protective coatings and the quality parameters of protective coating samples in water at different temperatures are presented. Based on the results of light spectroscopy, the coefficients of hydraulic friction and equivalent roughness were calculated, as well as an automated calculation using a specially developed program to assess energy savings during water transportation when using the Subcote FLP protective coating during the renovation of a steel pipeline

Keywords: pipeline, protective coating, roughness, light microscopy, profilometry, water quality indicators, energy saving

АНАЛИЗ ТРАНСФОРМАЦИИ ПАРАМЕТРОВ ШЕРОХОВАТОСТИ И ХИМИЧЕСКОГО СОСТАВА ЗАЩИТНОГО ПОКРЫТИЯ ТРУБОПРОВОДА ПРИ ЕГО РЕМОНТЕ

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Аннотация. Рассмотрены вопросы потенциальной трансформации шероховатости поверхности твердых образцов напыляемого защитного покрытия Subcote FLP, используемого в период бестраншейной реконструкции напорных трубопроводов. Представлена методика проведения опытов по исследованию динамики изменения шероховатости образцов во временном диапазоне путем их погружения в емкости с водой, дозировании в нее дезинфектанта и обработкой воды на магнитной мешалке с последующим анализом поверхности образцов методами светоскопии и профилометрии. Выявлены и проанализированы изменения качественных характеристик образцов покрытий и химических показателей воды. Представлена динамика изменения коэффициента эквивалентной шероховатости защитных покрытий и качественных параметров образцов защитных покрытий в воде при разной температуре. По результатам светоскопии произведен расчет коэффициентов гидравлического трения и эквивалентной шероховатости, а также автоматизированный расчет по специально разработанной программе для оценки экономии электроэнергии при транспортировке воды в случае использовании защитного покрытия Subcote FLP при реновации стального трубопровода.

Ключевые слова: Трубопровод, защитное покрытие, шероховатость, светоскопия, профилометрия, показатели качества воды, экономия электроэнергии

INTRODUCTION

The issues of determining the roughness of the inner walls of pressure pipelines made of new materials, as well as its possible transformation during the long-term operation of engineering networks, are relevant, as they allow to identify such important characteristics as the values of the coefficients of equivalent resistance and hydraulic friction and, thereby, to substantiate the prospect of possible energy savings during water transportation [1].

An analysis of global experience in the operation and repair of water supply pipeline networks shows that to increase the reliability of pipeline systems, the most promising solution is to rehabilitate them by applying internal protective coatings of various types, including polymer sprayed materials. In the process of developing renovation projects for pipeline transport and their implementation, there is a need to obtain reliable data necessary to ensure the reliability of the restored pipelines by ensuring the appropriate hydraulic and strength characteristics of the restored networks, which acquire a two-layer structure after repair work [2, 3].

An analysis of the results of previously conducted studies shows that there are valid documents in the certification systems that describe the measurement procedures necessary to determine the hydraulic characteristics of pipelines with internal coatings [4]. At the same time, it is very important to determine the ability of protective coatings (internal linings) to maintain their hydraulic characteristics during long-term operation and not to negatively affect the quality of the transported water [5].

Given the significant extent of wear and tear on pipeline systems, where, according to data from the Ministry of Regional Development, more than 40% of water supply networks require immediate repair, the effectiveness of using new types of internal protective coatings for dilapidated pipelines using efficient and prompt trenchless methods becomes extremely relevant [6]. In order to prove the effectiveness of the use of certain types of polymer protective coatings and the absence of potential negative circumstances, such as chemical reactions between the coatings and the transported water, as well as changes in their hydraulic properties (such as changes in surface roughness), it is necessary to conduct a wide range of studies under dynamic conditions using appropriate models and special instruments.

In accordance with the available conformity certificates, protective polymer spray coatings do not change the composition of the pumped medium, maintaining the reliability of pipeline networks at a high level and reducing the negative impact on the urban environment due to repair work. Despite the thin layer of 3-8 mm, these materials can effectively fill in existing defects and increase the wear resistance of pipelines during the rehabilitation process. As a result, the internal surfaces of the restored pipelines tend to become less rough, improving the hydraulic performance of the pipelines. To prove this, the structure of the protective coatings is analyzed using a number of modern contact and optical methods that provide information about their roughness [7].

The objectives of this work were to conduct scientific research that confirms or refutes the noted facts using modern approaches and methods for determining and evaluating the hydraulic performance of protective coating samples.

METHODS AND MATERIALS

The sprayed organic protective coating Subcote FLP was used as the research materials. The coating has a sanitary and epidemiological expert opinion No. 77.01.12.P.014303.09.11 dated 22.09.2011, issued by the Department of the Federal Service for Supervision of Consumer Rights Protection and Human Welfare in Moscow, which allows the coating to be applied to the inner surface of pipelines in domestic and drinking water systems.

In the work, modern tools of contact and optical technologies, respectively profilography and

lightoscopy, were adopted as methods of roughness research. According to the results of these methods, the analysis and comparison of the obtained data was carried out, in particular, on the arithmetic mean deviation of the surface profile, the height of its irregularities, etc. with the subsequent calculation of the values of the coefficients of equivalent roughness of coatings in time before and after their special processing.

The essence of the experiments on studying the dynamics of changes in roughness was to process the samples of the protective coating on a small-sized installation, which was a glass cup (container) of the calculated height and diameter with a measured volume of 1 liter of drinking water (Figure 1). The samples of the protective coatings of certain sizes were rigidly placed in the cup near its wall (at the periphery).

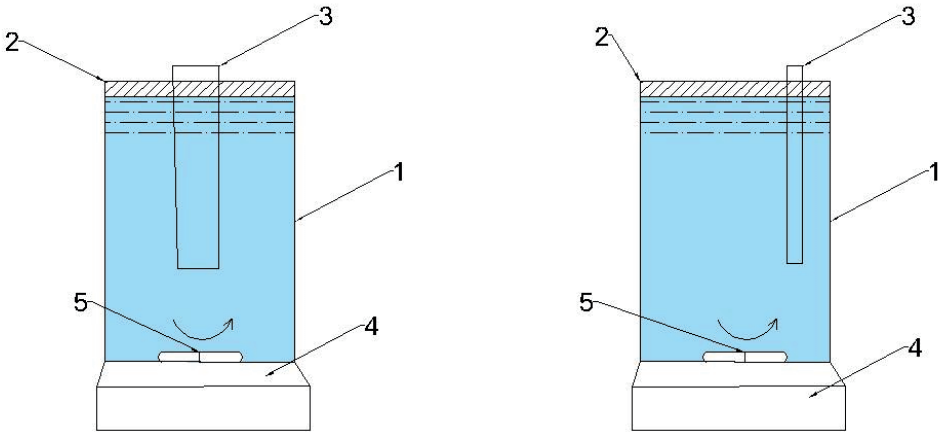


Figure 1. Layout of the apparatus elements on the magnetic stirrer (left – front view of the sample in the container; right – rear view of the sample) 1 - glass cup; 2 - rubber stopper; 3 - sample of a certain size, suspended near the edge of the cup; 4 - magnetic stirrer; 5 – anchor

The beaker was placed on a special device (magnetic stirrer), where the contents were mixed at a specific angular velocity ѡ (converted to linear velocity V or tangential velocity), ensuring a precisely defined contact time between the sample and the water, simulating the identical duration of water flow in a pipeline of the appropriate length and diameter at an optimal velocity of 1 m/s. The conversion of angular velocity to linear (tangential) velocity was performed using an online calculator in the standard program planetcalc.ru.

When conducting experiments on a magnetic stirrer, specially prepared solid samples of the Subcote FLP internal protective coating to be sprayed were examined. The dimensions of the samples were (2.0 x 8.0), and their contact area with the water flow, taking into account the front and back sides, as well as the side surfaces, was 32 cm2. The one-time duration of sample processing in a glass of water on a magnetic stirrer was 2h 47 minutes, which corresponded to (simulated) the presence of water in a pipeline 10 km long and 1200 mm in diameter. These parameters are adopted for the need to ensure approximately equal conditions for the consumption of chlorine in time by a unit of surfaces (1 cm2) of samples and the contact area of the water flow during its transportation through the pipeline. In this case, the consumption of chlorine for the samples was 1/32=0.03125 L and for the simulation of the pipeline 11304000 / 376800000=0.03 L per 1 cm2 of the contact area of the pipeline walls with water.

As mentioned above, two alternative methods were used to study the roughness of the protective coating samples: the probe (contact) method and the optical (non-contact) method,

which have the same range of measured micro-irregularity heights (0.8 – 62.5 μm). These methods are relatively simple to use when processing measurement results.

The scanning electron microscope, the TESCAN MIRA 3 LMU scanning electron microscope and the Olympus GX53 inverted microscope, as well as the TR 100 portable roughness meter, were used as instruments for studying the above parameters. To determine the quality of water, an instrument base was used, including a Primelab PL-HR-atom magnetic stirrer, an ECOSTAB PC 233 analyzer for determining pH, salinity, electrical conductivity and water temperature.

It should be noted that, depending on the regulatory requirements for the disinfectant dose that provides a bactericidal effect during water disinfection, a certain amount of chlorine was artificially added to the water in the form of universal Aquabreeze water disinfection tablets. This ensured that the residual chlorine concentration remained at the required level for water sterilization after it left the water treatment plant, typically at least 1.0 mg/L [8].

The ultimate goal of the research is a comprehensive analysis of the possible transformation of the initial roughness and chemical composition of water over a certain time interval in a magnetic stirrer system, which provides a tangential flow of water as an analogy for the flow of water in linear objects (pressure pipelines) of the appropriate diameter and length. Additionally, the objective is to determine the effect of the duration of the sample's exposure to chlorinated water at a specific dose of the reagent on the roughness [9].

One of the tasks in conducting experiments and processing their results using automated programs was to indirectly assess the energy consumption during water transportation as a result of potential changes in the hydraulic characteristics of the protective coating samples over time and due to the impact of chlorine added to the water.

RESULTS

Below are the results of three research cycles, in particular:

- on the transformation of the equivalent surface roughness coefficients of Subcote protective coating samples based on parallel experiments using profilometry and light microscopy, followed by the calculation of the equivalent surface roughness coefficients of the coatings over time before and after their special treatment, as well as the recording of the arithmetic mean deviation of the surface profile, the height of its irregularities, etc. (I cycle);
- by changing the chemical properties of the surface of the protective coating samples, which leads to changes in the roughness profile heights in the transverse and longitudinal directions, as well as in the morphology (in this case, the structure and elemental chemical composition) of the samples, using electron microscopes to process the data, and by changing the water quality indicators before and after the experiments on the magnetic stirrer (cycle II);
- to assess the energy consumption during water transportation as a result of potential changes in the hydraulic characteristics of protective coating samples over time and due to the impact of chlorine derivatives using modern electronic models (III cycle) [10].

Cycle I.

1. The results of profilometry experiments (on the TR 100 roughness meter) on samples of protective coatings (in cold and hot water) in dynamics and the analysis of the obtained results on the determination of the coefficients of equivalent roughness KE:

- on the initial sample (1) in nature - KE = 0.0386 mm;
- on sample (2) with a chlorine dose of 1.07 mg/L in the initial cold (200 C) water and a processing time of 2 h 47min in the agitator - KE = 0.02428 mm;
- on sample (3) with a chlorine dose of 1.0 mg/L in the initial cold (200 C) water and a double processing time of 2x(2 h 47min) - KE = 0.02085 mm;

- on sample (4) with a chlorine dose of 1.0 mg/l in the initial hot water (500 C) and a treatment duration of 2 h 47m - KE = 0.02225 mm.

The analysis of the data presented above shows a downward trend in the equivalent roughness coefficients as a function of the time spent by the samples in chlorinated water, with the most pronounced effect occurring when the sample is placed in hot water, where the disinfectant dose and the duration of the sample's stay in the magnetic stirrer are the lowest.

2. The results of light microscopy experiments (using an Olympus GX53 microscope) on samples of protective coatings (in cold and hot water) in dynamics and the analysis of the results obtained to determine the equivalent roughness coefficients KE:

- on the original sample (1) in nature - KE = 0.0372 mm;
- on sample (2) with a chlorine dose of 1.07 mg/l in the initial cold (200 C) water and a processing time of 2h 47min in the agitator - KE = 0.0228 mm
- no studies were conducted on sample (3);
- on sample (4) with a chlorine dose of 1.0 mg/l in the initial hot (500 C) water and a processing time of 2h 47m - KE = 0.0217 mm.

As in the previous calculation point, the analysis of the data presented above shows a downward trend in the equivalent roughness coefficients as a function of the time the samples spent in chlorinated water. The greatest reduction in roughness is achieved when the samples are treated with hot water.

When comparing the results of points 1 and 2 for the three samples, it can be noted that the difference in the obtained data for determining the equivalent roughness coefficient KE is as follows:

- for the initial sample (1), the difference in the values of the equivalent roughness coefficient is 0.0386-0.0372 = 0.0014 mm or 3.76%;
- for sample (2), the difference is 0.02428-0.0228=0.00148 mm or 6.5%
- for sample (4), the difference is 0.02225-0.0217=0.00055 mm or 2.53%

Thus, in three experiments, the discrepancy in the KE readings ranged from 2.53% to 6.5%, which indicates that the results of profilometry and light spectroscopy experiments can be used interchangeably to determine the equivalent roughness coefficient of the samples.

The nature of the irregularities (heights) was determined using light microscopy on an inverted Olympus GX53 microscope. There were no roughness protrusions on the samples, respectively, in the longitudinal and transverse directions, which amounted to: 40-120 and 43-103 microns for sample (1), 120-195 and 65-158 for sample (2); 158-210 and 125-208 microns for sample (4). At the same time, the steps for fixing irregularities in samples (1) and (4) were 70, respectively and 200 microns, which can be characterized as a transition from more frequent to more rare, which means that it may indicate some straightening of the roughness of the samples over time during treatment in water with chlorine.

Figure 2 graphs show the transformation of surface irregularities on samples (1) and (4) as sample roughness profiles in the longitudinal direction.

The graphical dependencies presented in Figure 2 indicate that, compared to sample (1), sample (4) exhibits a peculiar "growth" in the average profile height: from (40+120)/2=80.0 μm to (160+210)/2=175 μm. Thus, an increase in the average height of the profiles due to "growths" on the surface of the samples does not lead to an increase in the surface roughness, as the step of the roughness protrusions (irregularities), as noted above, increases from 70 μm to 200 μm, which contributes to the local smoothing of the surface between the peaks of the roughness protrusions.

This phenomenon can be explained by the reaction of chlorine with the sample (see cycle II) or by the deposition of chlorine salts on the surface of the sample, which is a kind of inlay that has a positive effect in this case, as the average deviation of the Ra profile was 9 and 6 μm for samples (1) and (4), respectively.

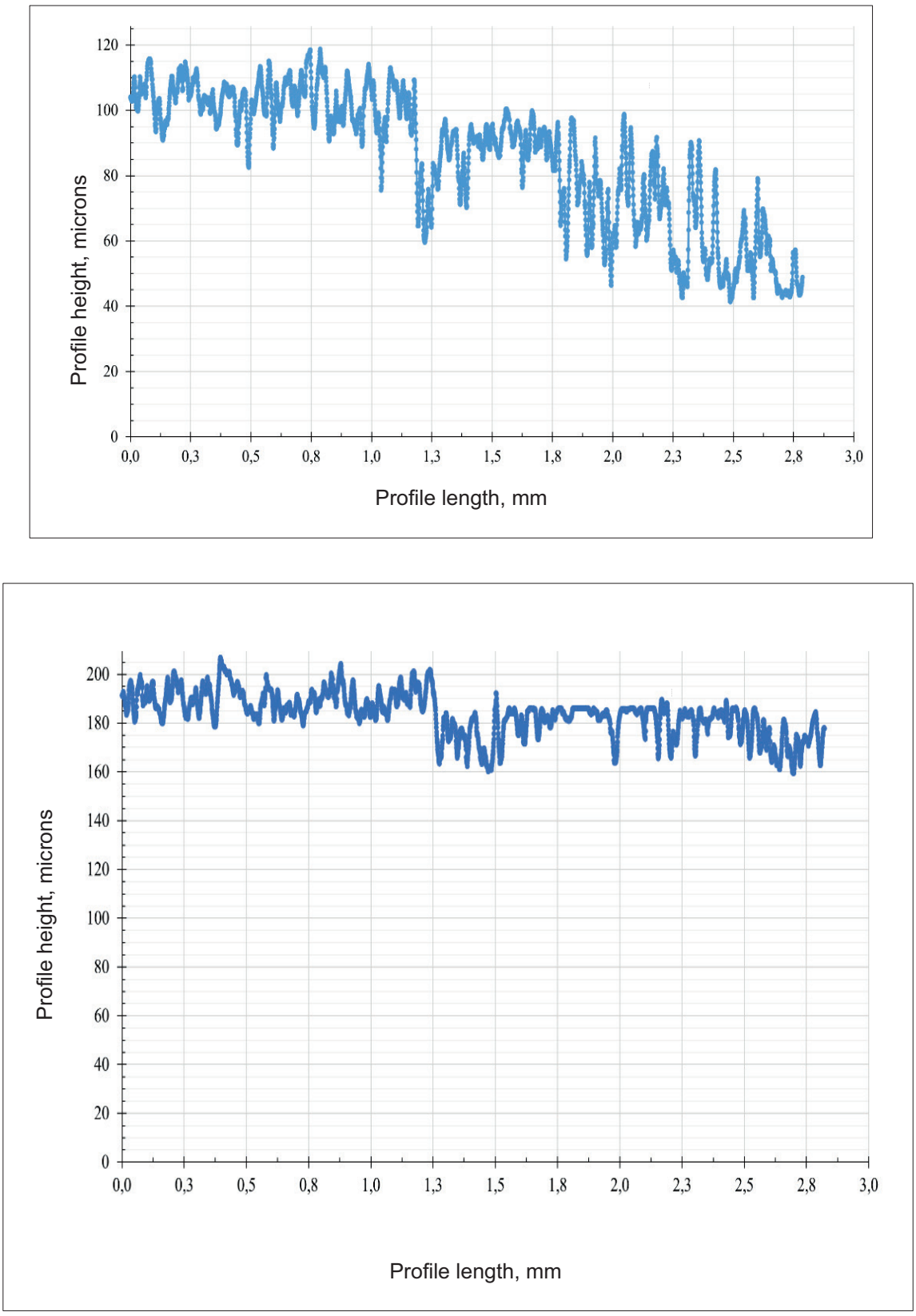


Figure 2. Illustration of the surface profiles of samples (1) and (4), respectively, in the longitudinal direction: from top to bottom before treatment in chlorinated water and after treatment

Thus, it can be concluded that when processing samples on a device with a magnetic stirrer, the possibility of the phenomenon of "straightening" of a rough surface with filling of pores between the peaks of roughness (conditionally called "voids or dips") is not excluded. This suggests that the coefficient of equivalent roughness of the sample may decrease over time, i.e., during long-term operation of a pipeline with a protective coating.

Cycle II.

In this cycle of experiments, the issues of changing the morphology of samples before and after processing in chlorinated water on a magnetic stirrer, as well as the consideration and influence of the quality indicators of water and its temperature on the processes of transformation of the surface of samples, are examined.

In this series of experiments, a TESCAN MIRA 3 LMU scanning electron microscope was used, as well as a device for chemical control of water quality indicators (Ecostab PC 233 analyzer).

The results of experiments with coating samples on an electron microscope showed that there is a change in the Cl (chlorides) indicator on the surface of the samples, with an increase after treatment in water on an apparatus with a magnetic stirrer, and a similar change in the concentration of calcium Ca and the appearance of potassium K.

In the summary Table 1, there are printouts of the output parameters for the presence of chemical elements in the composition of the studied samples, which indicate a change in their chemical composition after treatment on a magnetic stirrer.

Table 1. Illustration of the dynamics of changes in the weight and atomic composition of chemical elements in samples depending on the time and temperature of their processing: on the left, the initial sample (1), in the middle, the sample (2), and on the right, the sample (4)

Element	Weight, %	Atomic, %
C	72.05	78.94
O	23.49	19.32
Na	0.13	0.07
Mg	0.04	0.02
Al	0.15	0.07
Si	1.15	0.68
Cl	0.18	0.07
Ca	2.49	0.82
Results	100	

Element	Weight, %	Atomic, %
C	66.33	74.26
O	27.77	23.33
Na	0.44	0.26
Mg	0.07	0.04
Al	0.18	0.09
Si	1.77	0.85
Cl	0.47	0.18
Ca	2.61	0.88
K	0.36	0.12
Results	100	

Element	Weight, %	Atomic, %
C	65.8	73.94
O	27.91	23.54
Na	0.26	0.15
Al	0.25	0.12
Si	1.82	0.88
Cl	0.76	0.29
Ca	2,98	1,00
K	0.23	0.08
Results	100	

A characteristic feature of the data presented in Table 1 for each sample is:

- sample (1) has a relatively low content of the chemical element chlorine (0.18%) and a predominance of the weight fraction of carbon 72.05% and oxygen 23.49 %;
- in sample (2), compared to sample (1), the concentration of chlorine in the protective coating material increased from 0.18% to 0.47%, i.e., by 2.61 times, while the weight fractions of carbon decreased by 7.94% (72.05-66.33) and the weight fraction of oxygen increased by 15.4% (27.77-23.49), and potassium appeared (0.36%);
- in sample (4), compared to sample (1), the concentration of chlorine in the material increased from 0.18% to 0.76%, i.e., by 4.22 times, while the weight fractions of carbon decreased from 72.05% to 65.8%, i.e., by 1.09 times, and the weight fraction of oxygen

increased by 1.19 times (from 23.49% to 27.91%), while the weight fraction of potassium decreased slightly (0.23%).

It should also be noted that a similar phenomenon of increasing the calcium concentration in the coating material is observed from sample to sample: in sample (2) compared to sample (1), its concentration increased by 4.8%, and in sample (4) by 19.7%.

Below are theoretical calculations illustrating the analysis of changes in the chemical properties of water and samples (2) and (4) after their contact with chlorine water in a beaker on a magnetic stirrer.

Regarding the chlorine reaction with sample (2), it should be noted that the initial value of total chlorine in the water was 1.07 mg/L (before the experiment) and decreased to 0.49 mg/L, remaining in the water as free chlorine that provided water disinfection. Therefore, 1.07-0.49=0.68 mg/L of chlorine should react with sample (2).

On the other hand, the initial value of residual chlorine in the water before the experiments, according to the measurements, was 0.95 mg/L, and after the experiment it decreased to 0.35 mg/L. Then it can be assumed that residual chlorine in the amount of 0.95-0.35=0.6 mg/L reacted with the sample.

Comparing the values obtained from the analysis of the transformation of various forms of chlorine in water, we can note the similarity of the concentration of total chlorine (0.68 mg/L) and residual chlorine (0.6 mg/L), which reacted with the sample. The difference in the results was 11.76%.

Regarding the increase in water mineralization during the experiments, the following can be noted: the initial water mineralization was 282 mg/L (before the experiment), and it increased to 286 mg/L after the experiment, resulting in a slight difference of 4 mg/L. However, this difference is consistent with the formation of chlorides and insoluble calcium salts, which can precipitate on the surface of the sample, leading to incrustation.

In terms of other chemical indicators of water, the following trend should be noted:

- the redox potential (ORP) of the initial water was 20 mV, and after the experiment it was 9 mV;
- the electrical conductivity of the water before the experiment was 397 μS/cm, and after it was 402 μS/cm; the difference of 5 μS/cm indicates an increase in mineralization, including the formation of chlorine salts, which increase the conductivity of the current;
- the pH value of the water before the experiment was 6.8, and after it was 7.02; the difference of 0.22 indicates a near-neutral environment.

Similar trends can be observed in the reaction of chlorine with sample (4), but with some notable differences.

It should be noted that the initial value of total chlorine introduced into the water at a dose of 1 mg /l a few seconds before the experiment was 0.27 mg/l, i.e. there was an almost instantaneous decrease in its concentration at elevated temperature; after the experiment, the concentration of total chlorine decreased to 0.06 mg/l, which may indicate, for example, an active reactions of chlorine with the sample, which confirms the hypothesis of a tendency to increase profile heights due to the growth of precipitating salts (see Figure 2); the initial value of residual chlorine in water was 0.02 mg/l (before the experiment), and the final value of residual chlorine was 0.00 mg/l (after the experiment); thus, all residual chlorine is also reacted with a sample in the amount of 0.02 mg/l and disappeared from the water.

Regarding the increase in water mineralization during the experiments, the following can be noted: the initial water mineralization was 297 mg/L (before the experiment), and it increased to 306 mg/L after the experiment, resulting in a difference of 9 mg/L, which is consistent with the formation of salts (chlorides) that can precipitate on the surface of the sample, contributing to incrustation phenomena.

In other chemical indicators of water, the following trend should be noted:

- the redox potential (ORP) of the initial water was 13 mV, and after the experiment -21 mV, which indicates the ionization of water, i.e. a

sufficient amount of charged ions in it to attract and neutralize the harmful excess acids;
- the electrical conductivity of the water before the experiment was 420 μS/cm, and after it was 430 μS/cm; the difference of 10 μS/cm indicates an increase in mineralization, including the formation of salts in the water, which increase the conductivity of the current;
- the pH value of the water before the experiment was 6.92, and after it was 7.46; the difference of 0.54 indicates a transition of the water from a near-neutral to a slightly alkaline environment.

Cycle III.

The results of the experiments in this cycle were aimed at describing the expected phenomena of inscription as a positive phenomenon that ultimately contributes to reducing the coefficient of hydraulic friction λ and thus leads to a decrease in energy consumption in the case of using the studied coating material for repairing high-pressure steel pipelines that transport drinking water.

Regarding the possible energy savings E (kWh) during water transportation, it can be noted that due to the potential changes in the hydraulic characteristics λ of the protective coatings, the following is observed:
- for the initial period of pipeline operation with a diameter of d (m)

$$\lambda i = 1/(2 \lg d / KEi + 1{,}14)2 = $$
$$=1/(2\lg 1.2 / 0.0000372+1.14)2 = 0.00969 \quad (1)$$
$$Ei = 0.81 \cdot Kt \cdot Q3 \cdot L \cdot \lambda i \cdot 24 \cdot 365 / (d\ 5\ \eta) = $$
$$= 443\ 830.8 \text{ kWh / year} \quad (2)$$

- after a long period of operation of a pipeline with a diameter of d (m) in the future

$$\lambda f=1/(2\lg d/ KEf +1.14)2 = $$
$$=1/(2\lg 1.2/0.0000318+1.14)2 = 0.00943 \quad (3)$$
$$Ef =0{,}81 \cdot Kt \cdot Q3 \cdot L \cdot \lambda f \cdot 24 \cdot 365 / (d\ 5\ \eta) = $$
$$=431\ 922.1 \text{ kWh / year} \quad (4)$$

where Q is the flow rate of water supplied by the pipeline, m3/s; KEi and KEf are the initial and prospective coefficients of equivalent roughness, m, respectively; η is the efficiency coefficient of the pumping unit; 24 is the number of hours the pump operates per day, h; 365 is the number of days in a year; L is the length of the pipeline, m; Kt is the correction factor for the change in water density with temperature.

The presented calculated data were obtained using the Prandtl formula [11], which displays the change in the hydraulic friction coefficient λ for the initial (1) and final (3) periods of operation, and the data from formulas (2) and (4) were obtained using the calculated dependence of energy consumption in the pipeline [6], taking into account the expected values of the hydraulic friction coefficient λ, which were calculated using formulas (1) and (3) using the experimental data obtained from the transformation of the equivalent resistance coefficient KE based on the operation of the small-sized installation.

It should be noted that the calculation of energy consumption E (kWh/year) was performed for a real pressure pipeline with a diameter of d=1.2 (m), a length of L=10000 (m), a water flow rate of Q=1.131 (m3/s), a pump efficiency of η=0.9, a water temperature of T=200 C, and a coefficient of thermal expansion of Kt =0.99923. Thus, it has been calculated that over time, the consumption of electricity during the transportation of water through a pressure pipeline will decrease by 443,830.8-431,922.1=11,908.7 kWh per year due to the reduction in the roughness of the protective coating. For example, if the cost of electricity for industrial enterprises is 1.57 rubles per kWh, the savings in money can amount to 11,908.7·1.57=18 696.7 rubles.

An automated program [12] has been developed and patented for complex energy and hydraulic calculations using the above-described methodology, which includes three cycles of experimental research.

CONCLUSIONS

1. Conducted on a small-sized installation field studies on the assessment of possible transformation of samples of the Subcote FLP polymer coating with reference to the real

conditions of their operation as protective coatings in pipelines during the period of trenchless repair, as well as complex processing of the obtained data using light microscopy and profilometry, allowed to establish a number of dependencies of the change in the coefficients of roughness on temperature conditions.

2. Based on the study of the dynamics of changes in the chemical parameters of water under the conditions of operation of a small-sized installation, assumptions are made about the interaction (reaction) of the samples of protective coatings with chlorine, which leads to a change in their morphology and hydraulic parameters.

3. Based on the results of comprehensive experiments with transformed samples of protective coatings, an energy calculation was performed for the case of their application in a real pressure pipeline during its trenchless renovation, which showed the possibility of saving electricity.

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