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ASSESSMENT OF THE TECHNICAL CONDITION OF A TREATMENT FACILITY AT A CHEMICAL ENTERPRISE

The object of research is a sewage well of a chemical enterprise. The chemical composition of the enterprise's wastewater, which is concentrated in the averaging unit, and the structural and elemental composition of concrete samples were determined. Upon completion of the experiment, proposals were made regarding the further operation of the chemical enterprise's treatment plant. It was found that the suspended solids content was higher in the first sample by 4.85%, and in the fifth – by 15.29%. The dry residue content was higher in the second sample by 20.18%, in the fourth – by 9.27%, and in the fifth – by 27.45%. The concentration of ammonium nitrogen is higher in the fourth experiment by 52.31%. The level of ammonium ions was higher in the fourth by 43.77%, nitrite ions in the second and third samples were higher by 16.67%, in the fourth by 383.33%, in the fifth by 983.33%. The increase in nitrate ions in the second sample was by 58.0%, in the third by 146.0%, in the fourth by 276.0%, in the fifth by 520.0%. APAR increased in the second water sample by 306.0%, in the third by 422.0%, in the fourth by 250.0%, in the fifth by 190.0%. The level of total iron is higher in the second group by 2288.89%, in the third – by 970.37%, in the fourth – by 1075.92%, in the fifth – by 1459.26%. The study by the X-ray fluorescence method showed that the CaO content was lower in the first sample by 3.27%, the second – by 2.27%, the third – by 3.01%; Fe_2O_3 is higher by 20.09%, by 22.77%, by 24.11%, SiO_2 by 10.83%, by 2.27%, 3.01%, SO_2 was by 4.50%, in the second and third – by 4.05%, TiO_2 by 0.68%, by 12.50%, by 14.19%. X-ray diffraction analysis showed the presence of a large amount of gypsum and quartz in the concrete.

The conducted research is distinguished by the fact that chemical corrosion of the concrete treatment plant under the influence of wastewater was established. The practical significance of the results obtained is that the destruction of the surface layer of concrete as a result of corrosion was established. Preventive measures are proposed to prevent corrosion of the treatment plant.

Keywords: *chemical composition of wastewater, concrete corrosion, elemental composition, concrete structure.*

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1. Introduction

Wastewater from chemical plants contains a large amount of alkalis, acids and detergents, which can lead to the destruction of concrete structures of treatment facilities. To protect concrete structures of treatment facilities, special chemically resistant coatings (mastics) are used, which are applied to the surface of concrete in 2–4 layers. These protective mastics prevent chemical corrosion of concrete and thus provide protection of concrete structures of treatment facilities for 5–10 years, depending on the aggressive environment of wastewater. During the operation of the facility, the protective layer of mastic needs to be updated or replaced due to its destruction, which is why there is a need for regular technical inspection of treatment facilities in order to assess the condition of the protective coating.

The service life of treatment facilities is directly affected by the temperature and composition of wastewater entering the main well (averaging unit).

A program for the construction of treatment facilities was developed and proposed taking into account the problem of wastewater treatment [1]. However, the result of using this model in practice for comparison with existing ones is not yet known.

The aggressive influence of wastewater from enterprises can destroy concrete treatment and sewage structures. In case of improper technical operation, destruction may occur, this leads to the seepage of wastewater into the ground and aquatic bioresources.

In the work [2], the problem of decentralized treatment and reuse of wastewater was investigated. Field studies of urban and agricultural treatment facilities were conducted and recommendations were proposed. However, as for each specific research object, the list of preventive measures may differ radically.

The conducted research showed that wastewater in large cities contains a significant amount of pollutants, and among them are not only heavy metals [3] and halogens [4] but also antibiotic resistance genes [5] and microorganisms [6].

In the works [7, 8] it was shown that one of the reasons for the destruction of concrete structures due to the action of high-temperature organic oil was its biochemical corrosion due to the action of microorganisms. The conducted research of samples of the material of the structures of the buildings allowed to identify the causes and degree of destruction, to prove the reasons for the decrease in the strength of concrete, but no effective protection was proposed.

As shown in [9], microbial corrosion is one of the important problems of the destruction of concrete structures. In [10], the results of studies of the influence of microorganisms and the absorption of sulfides on the concrete of sewage structures inoculated with wastewater are presented.

A standardized test has been developed and proposed for use for the development of building materials operated in sewage conditions [11]. However, the research requires further testing in the conditions of different enterprises and the service life.

There are many studies that propose methods for improving the strength characteristics of concrete for the operation of concrete structures in aggressive environments [12]. But no study suggests restoring the protective layer of a chemically resistant coating (mastic) in existing concrete structures of treatment plants.

The considered works presented various construction structures of buildings and structures affected by corrosion, but none of them considered the influence of the chemical composition of wastewater on the elemental composition and structure of concrete.

The relevance of the work is to study the influence of wastewater on the concrete of the construction of a treatment plant. For this, an assessment of the technical condition of the well structure will be carried out for suitability for normal operation.

The object of research was a sewage well of a chemical enterprise.

The aim of research was to assess the technical condition of the well in order to provide recommendations for its further operation.

To achieve the aim and conduct relevant studies, the following objectives were solved:

– to determine the chemical composition of the wastewater of the enterprise, which is concentrated in the averaging unit;
– to investigate the structural composition of the averaging unit concrete samples by X-ray diffraction;
– to determine the elemental composition of the concrete samples of the monolithic reinforced concrete of the well;
– to develop technical recommendations for the further operation of the structure.

2. Materials and Methods

2.1. Determination of the chemical composition of wastewater concentrated in the averaging unit

Technical inspection of the building structures of the tank (averaging unit) was carried out on the territory of a chemical enterprise in the Sumy region (Ukraine). The tank structure is made of monolithic reinforced concrete and consists of two parts: upper and lower (Fig. 1). The inner surfaces are waterproofed with 3 layers (HYDROZIT type "BS").

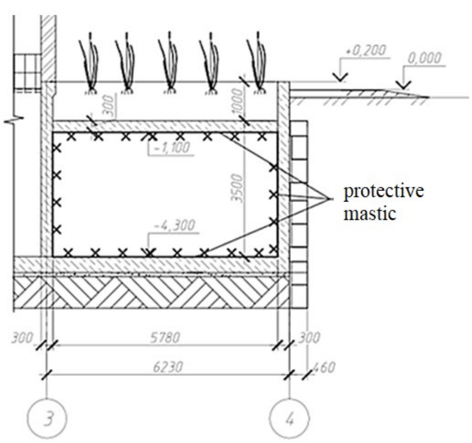

Fig. 1. Scheme of zones for applying protective mastic in a well (averaging units)

Laboratory studies of water were conducted at the Department of Building Structures and in the Research Laboratory of POLYMERASE Chain Diagnostics of Sumy National Agrarian University (Ukraine). Water samples were taken every ten days and compared with design data. Analysis of pollutants in wastewater was carried out using colorimetric, fluorimetric, gravimetric, potentiometric and titrimetric methods. The pH indicator was determined by the potentiometric method [13].

2.2. Research of the structural composition of samples of concrete of the mediator by X-ray diffraction

The research was conducted in the laboratory of the Department of Radiation Biophysics of the Institute of Applied Physics of the NAAS of Ukraine (Sumy, Ukraine). The PANalytical CubiX^3 X-ray diffractometer (Netherlands) was used. The shooting was carried out in the range from 200 to 800, where 2θ is the Bragg angle. For the research, concrete samples were crushed to a size of 15–20 μm and placed in a sample holder. Bragg-Brentano X-ray focusing was used for the tests [14].

2.3. Determination of the elemental composition of concrete samples of monolithic reinforced concrete of the well

The research was carried out using an X-ray fluorescence analyzer (XRF) ProSpector 3 (Elvateh, Kyiv, Ukraine). The method is based on the registration of specific X-ray radiation of atoms of the test substance, which occurs when the sample is irradiated. The XRF analytical unit was fixed at a distance of 1.5 mm from the sample with an exposure of 30–60 s. Measuring the intensity of specific radiation of atoms makes it possible to calculate the concentration of the corresponding substance [15].

The Fisher-Student method was used for statistical analysis of the results obtained [16].

2.4. Development of technical recommendations for further operation of the structure

Assessment of the integrity of the protective layer of waterproofing was carried out on the surface of the concrete tank of the averaging unit. The results of studies of the chemical composition of the enterprise's wastewater, the structural and elemental composition of concrete samples of the treatment plant were also taken into account. Based on the results of the assessment of the technical condition of the structure, recommendations were given for preventing concrete corrosion.

3. Results and Discussion

3.1. Research on the chemical composition of the enterprise's wastewater, which is concentrated in the averaging unit

In order to clarify the causes of concrete corrosion, the provided data on the composition of wastewater were analyzed, and laboratory determinations of the hydrogen index of damaged concrete were carried out (Fig. 2).

It was found that the level of suspended solids in the second sample exceeded the design standards by 4.85%, in the fifth – by 15.29%. The dry residue, where determined, was higher than the norm in the second sample by 20.18%, in the fourth – by 9.27% and in the fifth – by 27.45%, compared to the design standard.

In the second, fourth and fifth samples there were more insoluble and dry substances. Studies [17] prove that a high concentration of toxic substances complicates water purification.

The concentration of ammonium nitrogen is higher in the fourth experiment by 52.31%, and in the fifth due to high turbidity it is not determined at all. The content of total ammonium nitrogen is an indicator of the total load on the aquatic environment. It shows pollution by feces or organic waste.

The content of ammonium ions is higher in the fourth sample by 43.77% and in the fifth sample is not determined due to high turbidity, compared to the design standard.

According to the design standards, nitrite and nitrate ions are not determined in water, however, a sufficiently high amount was observed in all experimental samples, therefore all others were compared with the first experimental sample.

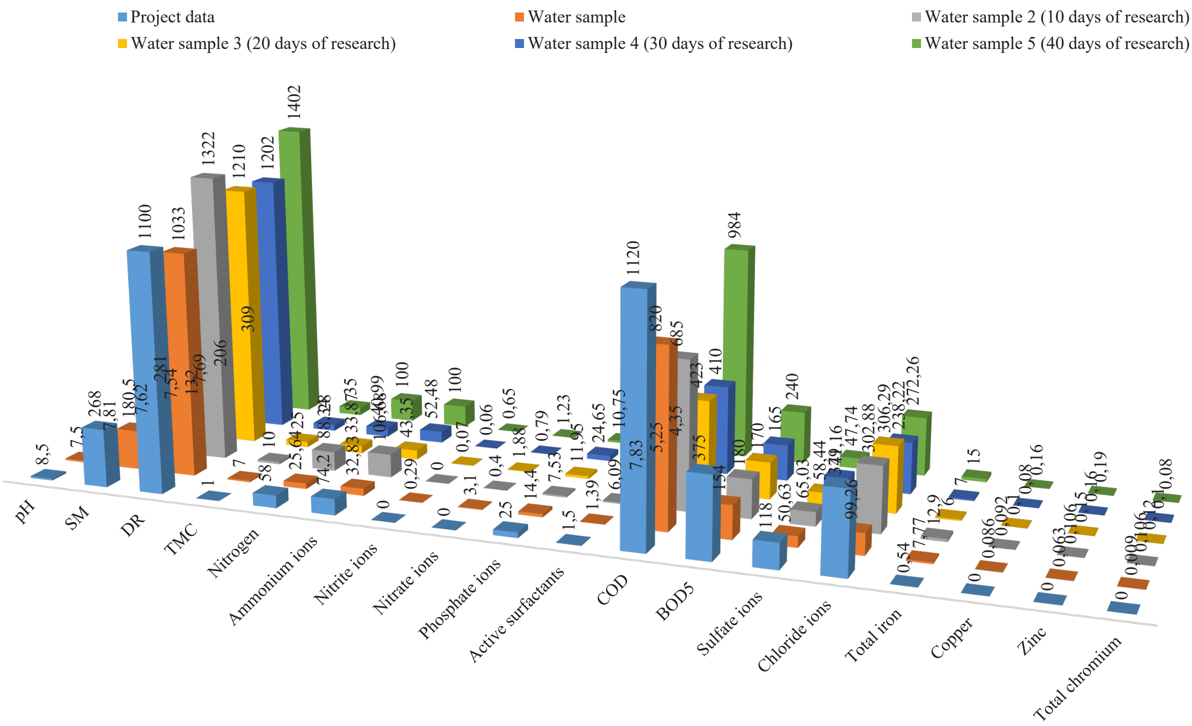

Fig. 2. Results of the study of the chemical composition of wastewater

Thus, the content of nitrite ions in the second and third samples was higher – by 16.67%, in the fourth – by 383.33%, in the fifth – by 983.33%, compared to the first experimental sample. The presence of nitrites in the water is a consequence of intermediate nitrification, indicating decay and active rotting, which is very toxic. The progressive increase in nitrate ions in the second sample by 58.0%, in the third – by 146.0%, in the fourth – by 276.0%, in the fifth – by 520.0%, compared to the first sample. The final product of nitrification is nitrate, the increased level of which in water is a sign of long-term pollution, mineralization which can penetrate into groundwater.

The content of phosphate ions in all experimental water samples was lower than the design norm. The content of synthetic surfactants (SSA) increased in the second water sample by 306.0%, in the third – by 422.0%, in the fourth – by 250.0%, in the fifth – by 190.0%, compared to the norm. The problem of untreated wastewater with a high content of suspended solids worsens the quality of water in reservoirs [18].

The concentrations of components in the wastewater of the enterprise that can be aggressive towards concrete and metal, namely ions Cl^- and SO_4^- do not exceed the design values, and are not significant. Wastewater in terms of pH and the presence of ions Cl^- and SO_4^- within the regulatory parameters in all test samples.

COD (chemical oxygen demand) and BOD_5 (biochemical oxygen demand for 5 days) were reduced, compared to the design norm. The increased level of BOD_5 shows the degree of water contamination by organic impurities. At the same time, wastewater, judging by the COD indicator, contains a significant amount of organic substances, which is several times higher than their presence in household wastewater [19].

The content of total iron exceeded the design indicators in the second group by 2288.89%, in the third – by 970.37%, in the fourth – by 1075.92%, in the fifth – by 1459.26%.

According to the design data, the water should not contain copper, zinc and chromium. However, in the first experimental indicator, copper was detected, and in the second its content increased by 6.97%. Zinc was contained in the first water sample and increased in the second by 68.25%. Total chromium was detected in the first water sample in a small amount, but in the second sample it increased by 1077.78%. Studies of concrete destruction in an aggressive environment have shown similar results [20].

The most favorable temperature range for the development of this type of chemical aggression is 12–30°C, especially above 16°C. The amount of hydrogen sulfide formed reaches a maximum at a wastewater pH of about 7.7 (the average pH value of the enterprise's wastewater is 7.5) and drops sharply when the pH exceeds 8.

3.2. Research results of the structural composition of concrete samples by X-ray diffraction

During a visual inspection of the upper part of the tank, no defects or damage to the concrete were detected.

During a visual inspection of the lower part of the tank, the presence of hydrogen sulfide in the gaseous medium was detected. Destruction of the surface layer of concrete, due to its corrosion, on surfaces above the average level of wastewater in the tank. The concrete in the indicated areas is a grayish-white mass that is easily removed by hand to a depth of up to 20 mm (concrete has zero strength). The presence of condensate and mucus on the surface of the concrete was recorded. The concrete is in a waterlogged state. There is corrosion damage to the metal ladder for access to the tank in the area above the middle of the wastewater in the tank. The thickness of the corrosion products is up to 5 mm.

Photos of damage to the concrete structures are presented in Fig. 3, 4.

Fig. 3. Destruction of the surface (protective) layer of monolithic concrete of the wall

Detachment of the coating waterproofing.

Concrete samples from the sewer well were also obtained (Fig. 4).

Fig. 4. Microscopic image of a concrete sample from the sewer, which has a pink color, indicating the presence of iron oxide (Fe_2O_3)

Concrete samples were examined using an X-ray fluorescence analyzer Fig. 5. As a result of the studies, it was found that the sample contains gypsum ($CaSO_4 \cdot 2H_2O$) and quartz (SiO_2), which confirms the studies conducted using an X-ray fluorescence analyzer (Table 1). Corrosion, as confirmed by studies [21], is induced by sulfates, leading to the formation of gypsum. Researchers [22] also note that concrete used in sewage systems is exposed to an aggressive environment. Sulfate enters the concrete and reacts with calcium ions, forming an expansion product of gypsum, and the constant accumulation of gypsum causes cracking and destruction of concrete [23]. The effects of chemical exposure were observed throughout the study, as a result of which there was chemical corrosion of monolithic reinforced concrete of a sewage well of a chemical enterprise.

To reduce the impact of wastewater on concrete, a number of measures were introduced that reduced the concentration of toxic substances in water, and accordingly, chemically induced corrosion of concrete.

3.3. Determination of the elemental concrete composition

The sample with the least damage was taken as the control sample (Table 1).

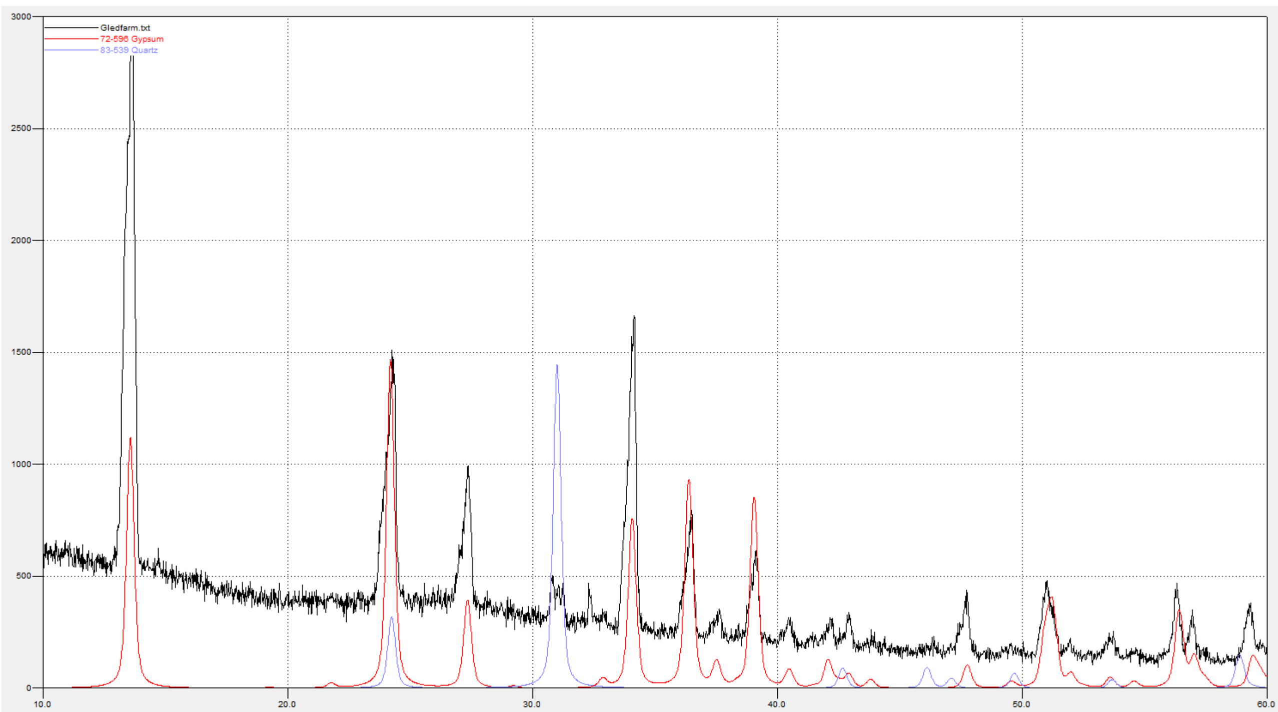

Fig. 5. Results of the study of a concrete sample using an X-ray diffractometer

Table 1

Elemental analysis of concrete samples of the averaging unit, $M \pm m$, $n = 5$

Indicators (%)	Control	Sample 1	Sample 2	Sample 3
Cao	78.00 ± 0.57	75.45 ± 0.63	76.23 ± 0.60	75.65 ± 0.67
Fe_2O_3	8.96 ± 0.34	10.76 ± 0.35	11.00 ± 0.31	11.12 ± 0.44
SiO_2	6.00 ± 0.14	5.35 ± 0.12	5.25 ± 0.13	5.25 ± 0.14
TiO_2	2.96 ± 0.64	2.94 ± 0.62	3.33 ± 0.75	3.38 ± 0.72
SO_2	2.22 ± 0.04	2.32 ± 0.05	2.31 ± 0.05	2.31 ± 0.05
K_2O	0.84 ± 0.75	1.00 ± 0.84	0.84 ± 0.67	0.86 ± 0.83
V_2O_5	0.44 ± 0.36	0.35 ± 0.32	0.41 ± 0.34	0.45 ± 0.39
SrO	0.34 ± 0.02	0.40 ± 0.03	0.40 ± 0.03	0.40 ± 0.03
Al_2O_3	0.23 ± 0.09	0.37 ± 0.09	0.34 ± 0.09	0.34 ± 0.09
CuO	0	0.24 ± 0.06	0.26 ± 0.04	0.26 ± 0.04
MgO	0.10 ± 0.09	0.13 ± 0.34	0	0
Nb_2O_5	0.08 ± 0.03	0	0.11 ± 0.04	0.11 ± 0.04
Cr_2O_3	0	0.13 ± 0.15	0	0
PbO	0.04 ± 0.03	0.30 ± 0.10	0.06 ± 0.03	0.06 ± 0.03
P_2O_5	0	0.06 ± 0.03	0.05 ± 0.03	0.05 ± 0.03
ZnO	0.05 ± 0.02	0	0.05 ± 0.02	0.05
Au	0.03 ± 0.02	0	0	0

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As a result of the conducted studies, it was found that the CaO content was lower in sample 1 by 3.27%, sample 2 by 2.27%, sample 3 by 3.01%, compared to the control. The content of calcium oxide shows the level of concrete destruction in the selected samples.

Studies [24, 25] confirm that increased corrosion of concrete contributes to a decrease in carbon.

Iron oxide (Fe_2O_3) was released by 20.09%, 22.77%, 24.11% more, respectively. The averaging unit is built of reinforced concrete, therefore, with a high degree of concrete corrosion, oxidation of the iron frame and the formation of iron oxide occur.

In concrete samples, silicon dioxide (SiO_2) was found to be more in the first sample by 10.83%, the second by 2.27%, and the third by 3.01%, compared to the control. The content of silicon dioxide shows the destruction of concrete into its constituent components, in particular sand.

The content of sulfur dioxide (SO_2) was higher in the first sample by 4.50%, in the second and third by 4.05%.

The presence of TiO_2 in concrete samples indicates its presence in wastewater and its content in concrete directly depends on the degree of destruction and penetration of the samples. Depending on the degree of penetration, titanium dioxide was contained more in the first sample by 0.68%, in the second by 12.50%, and in the third by 14.19%, compared to the control.

Similar studies by scientists prove the correlation dependence of the corrosion resistance of concrete on the degree of wastewater treatment [26, 27].

The samples also contained other elements, but in an amount of less than one percent, so they were not taken into account.

3.4. Technical recommendations for further operation of the structure

According to the results of the experiments, it was established that during the operation of the structure (averaging unit), corrosion damage to concrete occurred at a level above average in the lower tank. The damage detected in the concrete of the tank affects the durability and operability of the structure. The technical condition of the tank according to qualitative indicators (averaging unit) is generally classified as satisfactory. At the same time, the technical condition of the concrete of the lower part of the tank, above the average level of wastewater in it, is classified as unsuitable for normal operation.

Preventive measures to prevent corrosion of the concrete of the lower part of the tank are:

– periodic removal of sediment by mechanical or hydraulic methods;
– ensuring natural ventilation of the space above the surface of the wastewater;
– reducing the temperature of the wastewater;
– saturation of wastewater with oxygen (air);
– introduction of reagents, such as chlorine, nitrates, hydrogen peroxide, into the wastewater;
– alkalization of wastewater, for example, $Ca(OH)_2$.

The practical significance of the results obtained is that the impact of wastewater from a chemical enterprise on the concrete structure (mediator) has been established and measures for protection against corrosion in the future have been proposed.

The limitation of research is that the surveys were conducted within one facility.

The impact of martial law is that the research facility is currently operated under critical restrictions in the supply of water and electricity, which directly affect the security situation of the normal operation of the enterprise.

The prospect of further research lies in the implementation of the proposed measures to reduce corrosion of the research object.

4. Conclusions

1. As a research result of the chemical composition of the enterprise's wastewater, it was established that the suspended solids content was higher than the norm in the first sample by 4.85%, and in the fifth – by 15.29%. The content of dry residue was higher in the second sample by 20.18%, in the fourth – by 9.27% and in the fifth – by 27.45%. The concentration of ammonium nitrogen exceeded the permissible level in the fourth experiment by 52.31%. The content of ammonium ions exceeded the norm in the fourth by 43.77%, nitrite ions in the second and third samples – by 16.67%, in the fourth – by 383.33%, in the fifth – by 983.33%. The increase in nitrate ions in the second sample was 58.0%, in the third – 146.0%, in the fourth – 276.0%, in the fifth – 520.0%. The active surfactants increased in the second water sample by 306.0%, in the third – 422.0%, in the fourth – 250.0%, in the fifth – 190.0%. The content of total iron in the second group increased by 2288.89%, in the third – 970.37%, in the fourth – 1075.92%, in the fifth – 1459.26%.

2. The study of the structural composition of concrete samples by X-ray diffraction showed that the main composition of concrete was gypsum ($CaSO_4 \cdot 2H_2O$) and quartz (SiO_2), which indicates chemical corrosion.

3. The study of the elemental composition of concrete showed that the CaO content was lower in the first sample by 3.27%, the second by 2.27%, and the third by 3.01%. The Fe_2O_3 content was higher by 20.09%, 22.77%, and 24.11%. The presence of SiO_2 was 10.83%, 2.27%, and 3.01%, and SO_2 was 4.50%, in the second and third by 4.05%. Compared with the control, the TiO_2 content was higher by 0.68%, 12.50%, and 14.19%, respectively.

4. As a result of the experiment, damage was found in the concrete of the well (mediator), which affects the durability and operability of the structure. Based on the data obtained, technical recommendations were developed for the further operation of the structure. It was proposed to periodically remove sediment by mechanical or hydraulic methods and ensure natural ventilation. It was also recommended to reduce the temperature of wastewater and saturate it with oxygen (air). It was proposed to introduce reagents into wastewater, such as chlorine, nitrates, hydrogen peroxide and alkalization of wastewater, for example, $Ca(OH)_2$.

Conflict of interest

The authors declare that they have no conflict of interest regarding this research, including financial, personal, authorship or other nature, which could affect the research and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Authors' contributions

Liudmyla Tsyhanenko: Investigation, Validation, Writing – original draft; ***Oksana Shkromada:*** Conceptualization, Methodology, Formal analysis, Supervision, Writing – original draft, Writing – review and editing; ***Dmytro Volkov***: Validation, Investigation, Writing – original draft; ***Oleksandr Chekan***: Validation, Investigation, Writing – original draft; ***Valerii Lutskovskyi:*** Conceptualization, Methodology, Writing – original draft.

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