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CAUSES OF ACCELERATED PHYSICAL DETERIORATION OF A REINFORCED CONCRETE EQUALIZATION TANK IN THE BUILDING OF LOCAL WASTEWATER TREATMENT FACILITIES OF A PHARMACEUTICAL ENTERPRISE

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Abstract. The article investigates the causes of accelerated physical deterioration of a reinforced concrete equalization tank in the building of local wastewater treatment facilities (LWTF) of a pharmaceutical enterprise. The study demonstrates that the degradation of concrete structures results from the combined effects of chemical, physicomechanical, biological, and operational factors.

The operating features of the equalization tank, which provides the reception, temporary storage, and equalization of industrial wastewater with irregular inflow, are analyzed. The main factors affecting the durability of reinforced concrete structures are identified, including concrete chemical corrosion, reinforcement corrosion, biogenic sulfuric acid corrosion, cyclic hydrostatic loading, deterioration of protective coatings, and violations of the prescribed operating conditions.

Based on the analysis of recent national and international studies, together with the results of an in-situ technical inspection, the most vulnerable areas of the equalization tank were identified. These include the variable water level zone, the wall-to-base slab joints, pipeline penetration areas, and the gas space above the wastewater surface. It was determined that the above-water zone exhibits damage to the surface layer of concrete, delamination of the protective waterproofing, condensation, and slimy deposits. Laboratory analysis of corrosion products confirmed the acidic nature of the environment and the presence of sulfate ions. The detected damage and operating conditions indicate the development of biogenic sulfuric acid corrosion associated with the formation of hydrogen sulfide and its subsequent oxidation in the gas space of the tank.

The obtained results confirm the necessity of regular technical monitoring, timely restoration of anticorrosion protection, and the application of modern wastewater quality monitoring methods to ensure the reliable long-term operation of reinforced concrete equalization tanks at local wastewater treatment facilities of pharmaceutical enterprises.

Keywords: local wastewater treatment facilities, equalization tank, physical deterioration, concrete corrosion, structural durability, technical inspection, reinforced concrete structures.

Introduction. Pharmaceutical enterprises are characterized by significant water consumption and the generation of industrial wastewater with a complex chemical composition. This necessitates the use of local wastewater treatment facilities (LWTF) capable of ensuring stable and efficient operation of the treatment system.

One of the key elements of such facilities is a reinforced concrete equalization tank designed to receive, temporarily store, and equalize industrial wastewater before it enters subsequent treatment stages. The stable operation of LWTFs depends directly on the technical condition of this tank, as it ensures the equalization of the hydraulic and physicochemical characteristics of the effluent and reduces the negative impact of uneven and sudden discharges on the process equipment. A specific feature of equalization tank operation is continuous exposure to an aggressive environment. Industrial wastewater may contain residues of active pharmaceutical ingredients, surfactants, acids, alkalis, organic solvents, and other chemical compounds that create an aggressive environment for reinforced

concrete structures. Moreover, the cyclic filling and emptying of the tank results in varying hydrostatic loads on its structural elements, which, together with corrosion processes, gradually degrade the technical condition of the structures and shorten their safe service life.

The design service life of such tanks is generally 50 years [1]. However, technical inspections of similar facilities show that reinforced concrete equalization tanks often lose serviceability considerably earlier than this period. Typical damage includes deterioration of the concrete cover, reinforcement corrosion, delamination and destruction of protective coatings, and crack formation. Consequently, unplanned repair works, reconstruction of individual structural elements, or even replacement of process equipment may be required.

Analysis of national and international studies shows that the most intense corrosion processes in reinforced concrete structures of wastewater treatment facilities occur in zones of fluctuating industrial wastewater levels and at structural joints. Despite a significant number of studies devoted to the durability of concrete and reinforced concrete structures, the issue of determining the causes of accelerated physical wear of wastewater treatment tanks at pharmaceutical enterprises with consideration for the specific nature of their technological processes remains insufficiently studied, which is what prompted the need for this study.

Analysis of Recent Research and Publications. The durability of reinforced concrete structures operating in aggressive environments remains one of the relevant areas of modern research in the field of construction and operation of engineering structures. Local wastewater treatment facilities at industrial enterprises occupy a special place among such facilities, as their structures are continuously exposed to the combined effects of chemical, biological, and mechanical factors. The most vulnerable elements of these facilities include equalization tanks operating under prolonged contact with industrial wastewater of complex composition.

Domestic scientists pay considerable attention to researching the mechanisms of corrosion-induced deterioration of concrete and reinforced concrete in aggressive environments.

In [2], the authors note that the durability of reinforced concrete structures operating in aggressive environments is not determined by individual types of corrosion, but rather by the combined effect of carbonation, sulfate, and acid corrosion, the penetration of aggressive components into the pore structure of the concrete, and the development of reinforcement corrosion. The authors prove the necessity of applying comprehensive methods of corrosion protection and conducting systematic monitoring of the technical condition of structures throughout their entire service life.

Practical aspects of assessing the technical condition of reinforced concrete structures in wastewater treatment facilities are discussed in [3], which presents the results of a technical inspection of a local wastewater treatment facility at a chemical enterprise. The study identified characteristic defects in the structures, including deterioration of the protective concrete cover, corrosion of reinforcing bars, damage to protective coatings, and cracking. It is shown that the combined effect of a corrosive industrial environment and prolonged operation leads to a significant deterioration in the technical condition of the facility, confirming the need for systematic monitoring and the timely implementation of repair and restoration measures.

One of the most important areas of research on the durability of concrete structures in wastewater treatment plants is the study of the processes of their biochemical degradation [4, 5]. Researchers are particularly interested in the problem of biochemical corrosion of concrete structures, which is one of the most dangerous factors contributing to their degradation in aggressive environments. In [4], the authors studied the patterns of the effects of interrelated biochemical corrosion on concrete structures in the chemical industry. The authors found that the growth of thiobacteria and microfungi, combined with an acidic environment, causes the destruction of the cement paste, the formation of microcracks, and a gradual deterioration of the physical and mechanical properties of concrete. The results confirm that biological processes significantly accelerate the degradation of concrete structures and must be taken into account when assessing their durability. A recent review of the mechanisms of biogenic corrosion of cementitious composites in drainage systems, presented in [5], confirms the decisive role of microbiological processes in the degradation of concrete. In particular, the formation of hydrogen sulfide and its subsequent biological oxidation to sulfuric acid create conditions for the degradation of the

cement matrix and an accelerated reduction in the durability of structures. These patterns are also common for storage tanks at local wastewater facilities, where aggressive chemical components of wastewater and microbiological factors act simultaneously.

In [6, 7], the authors present current conceptions of the mechanisms underlying the development of biogenic sulfuric acid corrosion in concrete structures of sewer systems and wastewater treatment facilities. Based on a synthesis of the results of laboratory and field studies, the authors demonstrated that the most intense corrosive degradation of concrete occurs under the influence of biogenic sulfuric acid corrosion, which develops as a result of the metabolic activity of sulfur-oxidizing bacteria. The most vulnerable areas of the structures are the gas spaces of tanks, sections with fluctuating wastewater levels, and areas of localized moisture accumulation, as these create the most favorable conditions for the development of corrosion processes. In addition, the authors emphasize that improving the durability of concrete structures is possible only through a comprehensive approach that combines the use of effective protective coatings, systematic technical monitoring, and control of operational environment parameters.

Modern approaches to assessing biogenic corrosion of concrete structures and improving their durability are summarized in [8, 9]. The authors systematized current methods for studying microbiologically induced corrosion of concrete, analyzed its effect on the physicomechanical properties of structures, and performed a comparative assessment of the effectiveness of modern anticorrosion coatings. These findings demonstrate that the durability of concrete structures in wastewater treatment facilities largely depends on the prompt detection of initial signs of biocorrosion and the use of effective protective systems capable of limiting the penetration of aggressive components and the development of microbiological processes. These conclusions are supported by the results of field inspections of actual facilities. Thus, [10] reports that after only two years of operation of a reinforced concrete preliminary-treatment tank, significant delamination of epoxy protective coatings was observed, accompanied by corrosion deterioration of the concrete beneath the damaged areas to a depth exceeding 20 mm. The authors concluded that the main cause of premature physical deterioration of the structures was microbiologically induced corrosion, accompanied by the formation of sulfuric acid and subsequent degradation of the concrete structures.

Study [11] provides a theoretical explanation for selecting methods for the rehabilitation of sewer collectors depending on their technical condition, damage characteristics, and operating conditions. The authors detetmined the effectiveness of repair and restoration measures is determined by the results of a preliminary comprehensive technical inspection, which makes it possible to establish the degree of structural degradation, identify the nature and extent of damage, and substantiate the rehabilitation technology. It was shown that timely technical monitoring and the application of appropriate repair methods can significantly extend the service life of reinforced concrete structures of engineering facilities operating in aggressive environments. Study [12] considers a restoring technology for reinforced concrete and concrete sewer collectors damaged by microbiological corrosion using anchored polyethylene sheets. The proposed technology includes cleaning damaged surfaces of corrosion products, installing a protective polymer layer, and restoring the destroyed part of the structure by concreting. These conclusions are also relevant to equalization tanks at local wastewater treatment facilities, since their further effective operation likewise depends on timely diagnosis of the technical condition and a well-founded selection of restoration methods.

Our analysis of scientific research indicates significant progress in understanding corrosion deterioration processes in concrete and reinforced concrete structures of wastewater treatment facilities. At the same time, the causes of accelerated physical deterioration of equalization tanks at local wastewater treatment facilities of pharmaceutical enterprises remain under-researched. Most studies focus on individual mechanisms of concrete corrosion or on the technical aspects of industrial wastewater treatment, without considering the combined impact of operational factors on the durability of storage tank structures. Questions regarding the relationship between the composition of industrial wastewater from pharmaceutical enterprises, the operating conditions of storage tanks, and the rate of their physical deterioration remain insufficiently studied, highlighting the need for further research in this area.

The aim and objectives of the study are to determine the causes of accelerated physical deterioration of a reinforced concrete equalization tank at the local wastewater treatment facilities (LWTF) of a pharmaceutical enterprise based on the results of an in-situ technical inspection, analysis of the facility's operating conditions, and assessment of the effect of the aggressive industrial environment on the technical condition of its structural elements.

The stated objective was achieved by conducting an in-situ visual and instrumental technical inspection of the reinforced concrete equalization tank in accordance with [13] to determine the nature, location, and extent of defects and damage to its structural elements, to analyze the composition of industrial wastewater and the facility's operating conditions, and to identify the factors that caused accelerated physical wear and tear of the structures.

Materials and Methods. The study was based on the results of an in-situ technical inspection of a reinforced concrete storage tank at the on-site wastewater treatment plant of a pharmaceutical enterprise [14]; the design and construction documentation for the facility; data on its operating conditions; the structural features of the facility; and the composition of the industrial wastewater.

The subject of the study was a reinforced concrete equalization tank located within the on-site wastewater treatment plant of a pharmaceutical enterprise, designed to receive, temporarily store, and average industrial wastewater prior to its transfer to subsequent treatment stages; the tank has been in operation for 2.5 years. The rectangular tank measures 5.71 × 6.38 m and is 3.90 m high (Fig. 1).

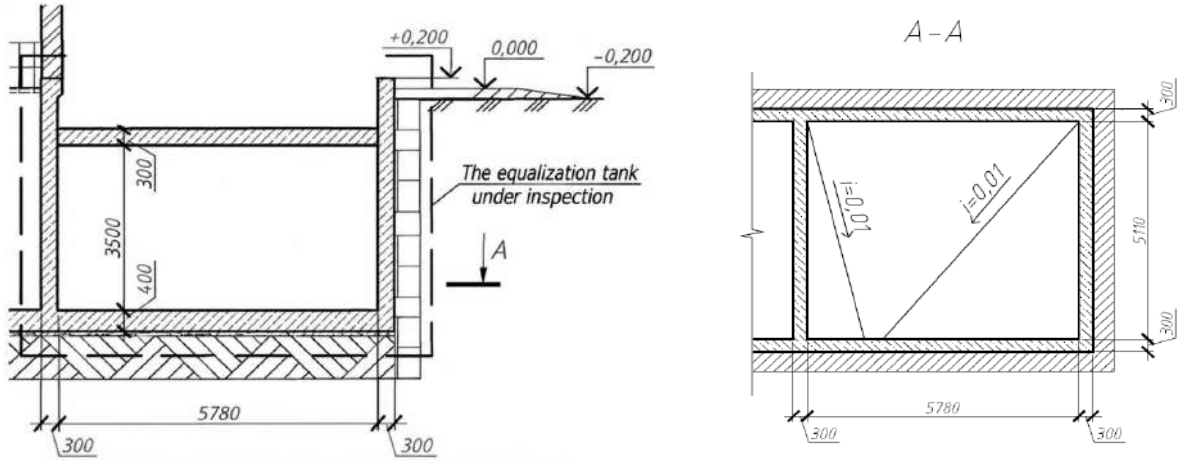


Fig. 1. Section through the LWTF building showing the inspected equalization tank

The structural design of the facility includes monolithic reinforced concrete walls and floors 300 mm thick, as well as a monolithic base 400 mm thick. The tank's load-bearing structures are made of heavy concrete of strength class C 25/30 (B30) with watertightness rating W6 and frost resistance rating F100, which ensure the necessary operational characteristics of the structure under the design operating conditions. To protect the tank's interior surfaces from the corrosive effects of industrial wastewater, the design provided for internal waterproofing consisting of three layers of a "GIDROZIT BS" mixture, each 1 mm thick [15]. The external surfaces of the structures were protected by applying two layers of bituminous mastic. A biofilter bed is located on the tank's roof, which is used for biological secondary treatment of wastewater. The roof includes two ventilation openings to remove gases from the interior of the tank and one access hatch designed to allow personnel access during inspection and maintenance of the facility. Inside the tank, there are two mechanical mixers, as well as a working pump and a standby pump, which ensure the mixing, homogenization, and pumping of wastewater to the subsequent treatment stages.

The research methodology involved a comprehensive assessment of the technical condition of the equalization tank, including inspection of the reinforced concrete walls, base slab and roof slab, utility penetration assemblies, expansion joints, internal protective coating, and external waterproofing. Special attention was paid to the detection of cracks, local deterioration of the concrete cover, reinforcement corrosion, delamination of protective coatings, loss of structural watertightness, signs of leaching, and biogenic corrosion.

Research Results. A preliminary inspection of the tank revealed a distinct, pungent odor of hydrogen sulfide in the gas space of the structure. After the tank was emptied, a visual and instrumental inspection of the lower part of the tank revealed defects on the inner surfaces of the storage tank walls in the area of fluctuating liquid levels, at the junctions between the walls and the bottom, and at the points where process pipelines pass through. Those areas are characterized by the most adverse operating conditions due to a combination of mechanical stress from the wastewater flow, high humidity, and constant contact of the structural surfaces with a corrosive environment. The destruction of the concrete surface layer due to corrosion on surfaces located above the average wastewater level in the tank appears as a grayish-white mass that can be easily removed by hand to a depth of up to 20 mm (the surface layer of concrete has completely lost its mechanical strength) (Fig. 2). No signs of corrosive deterioration of the concrete were found in the submerged part of the tank.



Fig. 2. Damage to the surface (protective) layer of the wall's monolithic concrete. Delamination of the coating waterproofing

Corrosion damage was observed on the metal access ladder in the section above the mid-height of the wastewater level in the tank. The thickness of the corrosion products was up to 5 mm. Visual inspection revealed an organomineral sediment layer up to 300 mm thick, as well as condensation and slimy deposits on the concrete surfaces in the above-water zone, confirming that the concrete was in a persistently water-saturated condition (Fig. 3).

Results and Discussion. Analysis of the composition and concentration of pollutants in the wastewater showed that the water pH was 7.54–7.81, while chloride and sulfate ion concentrations did not exceed the permissible values and therefore were not a direct cause of corrosion of concrete and steel. At the same time, the wastewater was characterized by a high content of organic matter (COD – 410–984 mg O_2/dm³, BOD_5 – 165–240 mg O_2/dm³), suspended solids (206–309 mg/dm³), total dissolved solids (1202–1402 mg/dm³), as well as the presence of sulfate ions, ammonium nitrogen, phosphates, and anionic surfactants. The COD/BOD_5 ratio was 2.48–4.10, indicating a significant proportion of poorly biodegradable organic compounds and creating favorable conditions for the development of anaerobic microbiological processes**.**

Laboratory analysis of concrete corrosion products showed that their pH was 2.7, which, according to [4], indicates the formation of a strongly acidic environment that is aggressive toward concrete and steel.

According to [11], based on pH values and the presence of ions Cl^- SO_4^-, the wastewater is non-aggressive toward concrete and steel. In addition, laboratory analysis of the concrete corrosion products revealed sulfate ions, confirming the occurrence of sulfate corrosion. This provides grounds to conclude that a corrosion-active gas environment develops in the above-water zone of the tank, despite the physicochemical composition of the industrial wastewater itself being non-aggressive toward concrete structures.



Fig. 3. Damage to the protective insulation. Delamination of the waterproofing coating. Efflorescence on the surface of monolithic concrete

Under anaerobic conditions, organic matter in the wastewater is decomposed by sulfate-reducing bacteria, resulting in the formation of hydrogen sulfide. After entering the gas phase, hydrogen sulfide is oxidized by sulfur-oxidizing bacteria to sulfuric acid, which reacts with the hydration products of the cement matrix to form gypsum. This results in a reduction in concrete alkalinity, deterioration of the cement matrix, and loss of strength of the surface layer of the structures. The most favorable conditions for this process are a temperature of 12–30 °C, a wastewater pH close to neutral, and a high content of organic matter, which correspond to the operating conditions of the tank under study.

The results indicate that the accelerated physical deterioration of the equalization tank is caused by the combined effect of a high organic load in the wastewater, formation of an aggressive gas environment, and operational factors that maintain persistent wetting of the structures and promote biogenic sulfuric acid corrosion. The predominant localization of damage in the above-water zone, the absence of corrosion in the submerged part of the tank, and the laboratory test results confirm that biogenic sulfuric acid corrosion is the governing mechanism of concrete deterioration.

Conclusions:

Analysis of scientific sources and the results of the in-situ technical inspection established that the accelerated physical deterioration of the reinforced concrete equalization tank at the local wastewater treatment facilities of a pharmaceutical enterprise is predominantly caused by the development of biogenic sulfuric acid corrosion resulting from hydrogen sulfide formation and the development of an aggressive gas environment in the above-water part of the tank.

It was established that the high content of organic matter in the wastewater, accumulation of organomineral sediment, and prolonged wetting of structural surfaces in the gas space of the facility promote microbiological processes and accelerate concrete degradation.

To improve the durability of the tank, systematic technical monitoring, adjustment of operating conditions, timely sediment removal, adequate ventilation of the gas space, and the use of effective anticorrosion protection systems are required.

Research Prospects. Given the established mechanism of biogenic sulfuric acid corrosion, the main approach to reducing the intensity of corrosion processes is to adjust the operating conditions of the tank. Therefore, further research should focus on the development and implementation of automated systems for monitoring environmental parameters in equalization tanks, including temperature, pH, hydrogen sulfide concentration, dissolved oxygen content, and organomineral sediment thickness. A promising area is the development of methods for prompt adjustment of facility operating conditions by regulating aeration, ventilation, wastewater mixing regimes, and the frequency of sediment removal, which will reduce the intensity of biogenic corrosion processes.

Another important area is the development of models for predicting the residual service life of structures based on technical monitoring data, enabling timely planning of repair and rehabilitation measures and improving the durability of equalization tanks through the development of effective anticorrosion protection systems.

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ПРИЧИНИ ПРИСКОРЕНОГО ФІЗИЧНОГО ЗНОСУ ЗАЛІЗОБЕТОННОГО РЕЗЕРВУАРА-НАКОПИЧУВАЧА БУДІВЛІ ЛОКАЛЬНИХ ОЧИСНИХ СПОРУД ФАРМАЦЕВТИЧНОГО ПІДПРИЄМСТВА

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Анотація. Стаття присвячена дослідженню причин прискореного фізичного зносу залізобетонного резервуара-накопичувача будівлі локальних очисних споруд (ЛОС) фармацевтичного підприємства. Дослідження показало, що деградація бетону конструкцій є наслідком одночасної дії хімічних, фізико-механічних, біологічних та експлуатаційних чинників.

Проаналізовано особливості роботи резервуара-накопичувача, що забезпечує приймання, тимчасове накопичення та усереднення виробничих стічних вод із нерівномірним режимом надходження. Визначено основні чинники, що впливають на довговічність конструкцій, серед яких хімічна та біогенна сірчанокислотна корозія бетону, корозія арматури, циклічні гідростатичні навантаження, руйнування захисних покриттів і порушення встановлених умов експлуатації.

На основі аналізу сучасних вітчизняних і зарубіжних досліджень та результатів технічного обстеження визначено найбільш уразливі ділянки резервуара, до яких належать зона змінного рівня рідини, стики стін із днищем, місця проходження трубопроводів і газовий простір споруди. Встановлено, що в надводній зоні спостерігаються руйнування поверхневого шару бетону, відшарування захисної гідроізоляції, конденсат і слизові відкладення. Лабораторне дослідження продуктів корозії підтвердило кислий характер середовища та наявність сульфат-іонів. Виявлені пошкодження та умови експлуатації свідчать про розвиток біогенної сірчанокислотної корозії, пов’язаної з утворенням сірководню та його подальшим окисненням у газовому просторі резервуара.

Отримані результати підтверджують доцільність регулярного технічного моніторингу, своєчасного відновлення антикорозійного захисту та застосування сучасних засобів контролю параметрів стічних вод для забезпечення надійної та тривалої експлуатації резервуарів-накопичувачів локальних очисних споруд фармацевтичних підприємств.

Ключові слова: локальні очисні споруди, резервуар-накопичувач, фізичний знос, корозія бетону, довговічність конструкцій, технічне обстеження, залізобетонні конструкції.

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