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RESEARCH OF MODERN CONSTRUCTION MATERIALS USED IN SEWER ENVIRONMENTS

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ДОСЛІДЖЕННЯ СУЧАСНИХ БУДІВЕЛЬНИХ МАТЕРІАЛІВ, ЩО ВИКОРИСТОВУЮТЬ У КАНАЛІЗАЦІЙНОМУ СЕРЕДОВИЩІ

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Abstract. *The paper considers sewer environment as one of the most aggressive media for traditional construction materials. The main mechanisms of concrete and reinforced-concrete deterioration are described with a focus on biogenic corrosion caused by the formation of hydrogen sulfide and its oxidation to sulfuric acid on moist surfaces in the crown of collectors. The results of recent Ukrainian research are summarised, in particular studies with organisational and technological solutions for open-cut rehabilitation of shallow sewers using corrosion-resistant self-compacting concrete, polymer concrete and anchored polyethylene liners.*

Modern groups of materials and protective systems applicable to sewer infrastructure are classified: sulfate-resistant cement concretes, concretes with mineral and polymer admixtures, polymer concretes and polymer-cement composites, polyethylene, PVC and polypropylene pipes, glass-reinforced plastic (GRP) pipes, HDPE-lined reinforced-concrete pipes, anchored HDPE sheets and internal polymer coatings. For each group, typical microstructural features, mechanisms of corrosion resistance, advantages, limitations and fields of application are discussed. Special attention is paid to the operating conditions of the Kharkiv sewer network, where most collectors are made of reinforced concrete and have already exhausted their design service life. A comparative framework is proposed to support the choice of rational materials for different types of facilities (trunk collectors, shafts, chambers, local networks and industrial sites) under Kharkiv conditions.

Keywords: *sewer environment, biogenic corrosion, corrosion-resistant concrete, polymer concrete, polymer pipes, GRP pipes, polymer coatings, anchored HDPE liners.*

Анотація. *У статті розглянуто особливості каналізаційного середовища як одного з найбільш агресивних щодо традиційних будівельних матеріалів. Проаналізовано основні механізми руйнування бетону та залізобетону, зокрема біогенну корозію, яка зумовлена утворенням сірководню та його подальшим окисненням до сірчаної кислоти на поверхні конструкцій. Узагальнено результати вітчизняних досліджень, виконаних у наукових школах м. Харкова та інших міст України, щодо підвищення довговічності каналізаційних колекторів,*

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присвячені організаційно-технологічним рішенням ремонту і відновлення колекторів водовідведення неглибокого залягання, застосуванню корозієстійкого самоущільнюючого бетону, полімербетону, анкерних поліетиленових листів і пневмоопалубки. Систематизовано сучасні будівельні матеріали і системи антикорозійного захисту, що можуть бути застосовані в каналізаційному середовищі: корозієстійкі цементні бетони на сульфатостійких і композитних цементах, бетони з мінеральними та полімерними добавками, полімербетони та полімерцементні композити, поліетиленові, ПВХ і поліпропіленові трубопроводи, склопластикові (GRP) труби, залізобетонні труби та колектори з поліетиленовою футерівкою, анкерні поліетиленові листи, а також полімерні захисні покриття на основі епоксидних і поліуретанових систем. Для кожної групи матеріалів наведено коротку характеристику мікроструктури, механізму корозійної стійкості, основних переваг і обмежень, а також типові сфери застосування в спорудах водовідведення. Особливу увагу приділено можливості використання зазначених матеріалів в умовах системи каналізації м. Харкова, де значна частина колекторів виконана із залізобетону та зазнала істотних пошкоджень унаслідок біогенної корозії. Запропоновано підходи щодо вибору раціональних матеріалів для різних типів споруд: магістральних колекторів, камер, колодязів, внутрішньоквартальних мереж і промислових майданчиків. Сформовано узагальнювальну таблицю, у якій наведено порівняльні характеристики основних матеріалів відносно довговічності, технологічності монтажу та доцільності застосування в умовах Харкова.

Ключові слова: *каналізаційне середовище, біогенна корозія, корозієстійкий бетон, полімербетон, полімерні труби, склопластикові труби, полімерні покриття, анкерні поліетиленові листи.*

Introduction. Safe and reliable operation of sewer networks is a key prerequisite for the sustainable development of modern cities. Reinforced-concrete collectors and ancillary structures are traditionally used in Ukraine for gravity sewer systems, including in the city of Kharkiv. A significant portion of these facilities was constructed several decades ago and has been exposed to long-term chemical, biological and mechanical impacts. As a result, many collectors demonstrate advanced deterioration of the crown zone, loss of bearing capacity and an increased risk of accidents.

Biogenic corrosion of concrete, driven by microbiological processes in wastewater and in the sewer atmosphere, is now recognised as one of the main causes of damage to underground sewer infrastructure. International and Ukrainian research show that in zones with high concentrations of hydrogen sulfide and condensate, the corrosion rate of conventional Portland-cement concrete can reach several millimetres per year, which rapidly leads to through-cracking of the protective layer and exposure of reinforcement.

In recent years Kharkiv and other Ukrainian cities have started to implement modern rehabilitation methods for sewer collectors. These include open-cut reconstruction using corrosion-resistant self-compacting concrete and polymer concrete, application of anchored HDPE sheet liners, installation of polyethylene or GRP pipes inside existing collectors, and the use of advanced polymer protective coatings. The variety of available materials and technologies makes it necessary to provide a structured comparison and to formulate recommendations for their rational use under local conditions.

Therefore, this paper focuses on a systematic analysis of modern construction materials used in sewer environments and on the justification of possible scenarios for their implementation in the sewer system of Kharkiv.

Literature review and problem statement. Ukrainian research groups have accumulated considerable experience in studying the durability of sewer structures and in developing new repair solutions. A series of works by Goncharenko, Aleinikova, Starkova, Iurchenko, and their co-authors [1-25] is devoted to organisational and technological schemes for the repair and rehabilitation of shallow collectors using corrosion-resistant self-compacting concrete, polymer concrete and sheet polymer materials. These studies introduced and tested an open-cut method for reconstructing the vault of collectors while pre-serving the existing invert, proposed pneumatic formwork for creating a new vault from clinker brick and polymer concrete, and justified the use of anchored HDPE liners for protecting load-bearing reinforced-concrete structures.

The monograph by Aleinikova, Goncharenko [1-6] and co-authors deals [7-25] with methodological principles for extending the service life of underground engineering networks. It considers the influence of aggressive environments, discusses the choice of materials for new construction and rehabilitation, and presents practical recommendations for utilities.

At the same time, international literature provides a broad overview of biogenic sulfuric-acid corrosion mechanisms and mitigation strategies, as well as of advanced materials for sewer systems. Recent reviews in leading journals analyse the formation of hydrogen sulfide, its oxidation to sulfuric acid and subsequent attack on the cement matrix, and summarise test methods for evaluating concrete resistance to biogenic corrosion. Other publications focus on the use of polymer concrete manholes and wet wells, geopolymer concrete pipes, HDPE-lined reinforced-concrete pipes and GRP pipes for highly aggressive wastewater conditions.

However, for practical design and rehabilitation of sewer systems in specific cities it is not sufficient to consider only general material properties. It is necessary to take into account local operating conditions, the state of existing infrastructure and the technological and economic constraints faced by municipal utilities. This motivates a comparative analysis of available materials in the context of the Kharkiv sewer network.

The aim and objectives of the study. The purpose of this research is to systematise modern construction materials that can be used in sewer environments and to perform a comparative analysis of their applicability to the rehabilitation and new construction of sewer facilities.

To achieve this purpose, the following objectives were defined:

– to describe the specific features of sewer environment and the main mechanisms of deterioration of concrete and reinforced-concrete structures;

– to classify the main groups of construction materials currently used worldwide and in Ukraine for sewer systems;

– to provide a concise technical description of each group, including micro-structural features, mechanisms of corrosion resistance, advantages and limitations;

– to compile a comparative table of materials in terms of durability, installation technology and suitability for different types of facilities;

– to formulate practical recommendations for the choice of materials for the conditions of the Kharkiv sewer network.

The main part of the study. ***Characteristics of sewer environment and corrosion mechanisms.*** Sewer wastewater is a complex multi-component medium that simultaneously exerts chemical, biological and physical–mechanical effects on structural materials. Typical parameters include variable pH, elevated concentrations of sulfates and chlorides, dissolved gases (H_2S, CO_2, H_2SO_4), significant organic load, elevated humidity in the gas phase and cyclic wetting–drying of the crown zone, presented in Fig. 1 [7, 15, 16, 19-25].

In gravity sewers, long residence time and insufficient ventilation lead to the formation of anaerobic zones in the wastewater where sulfate-reducing bacteria convert sulfates into hydrogen sulfide. The gas diffuses into the sewer atmosphere and accumulates in the crown zone. On moist surfaces, sulfur-oxidising bacteria convert H_2S into sulfuric acid, which attacks the cement matrix.

As calcium hydroxide and other hydration products dissolve and transform into gypsum and ettringite, the concrete surface softens, cracks and spalls. This process is accelerated by high humidity and temperature and by roughness that facilitates biofilm development (Fig. 2).

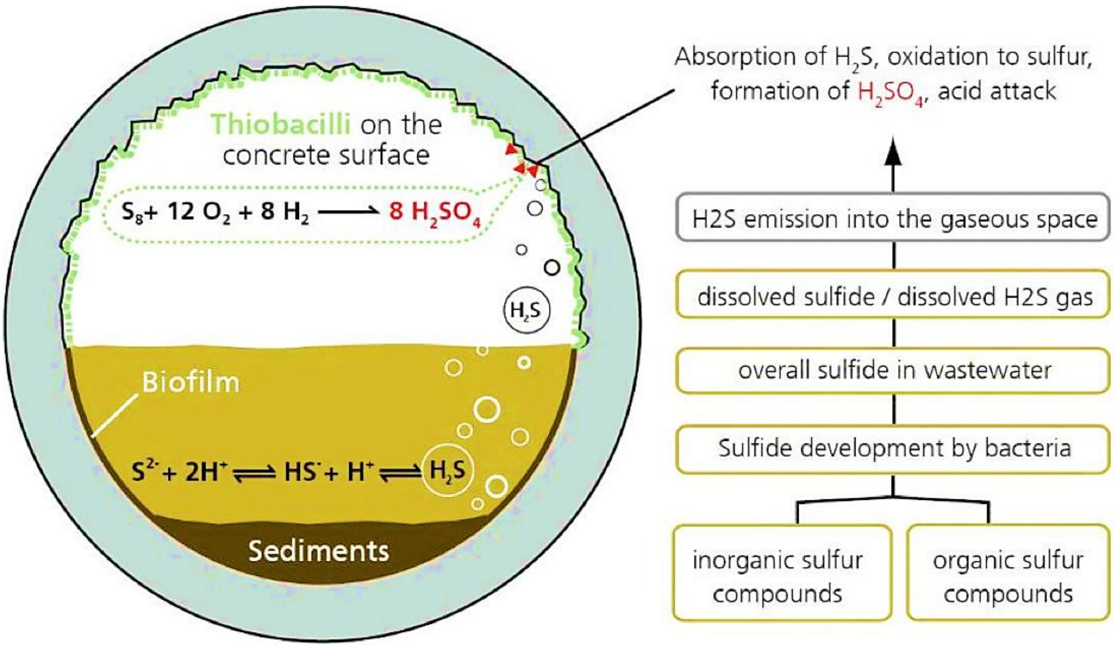

Fig. 1. Scheme of corrosion of concrete sewer tunnel linings

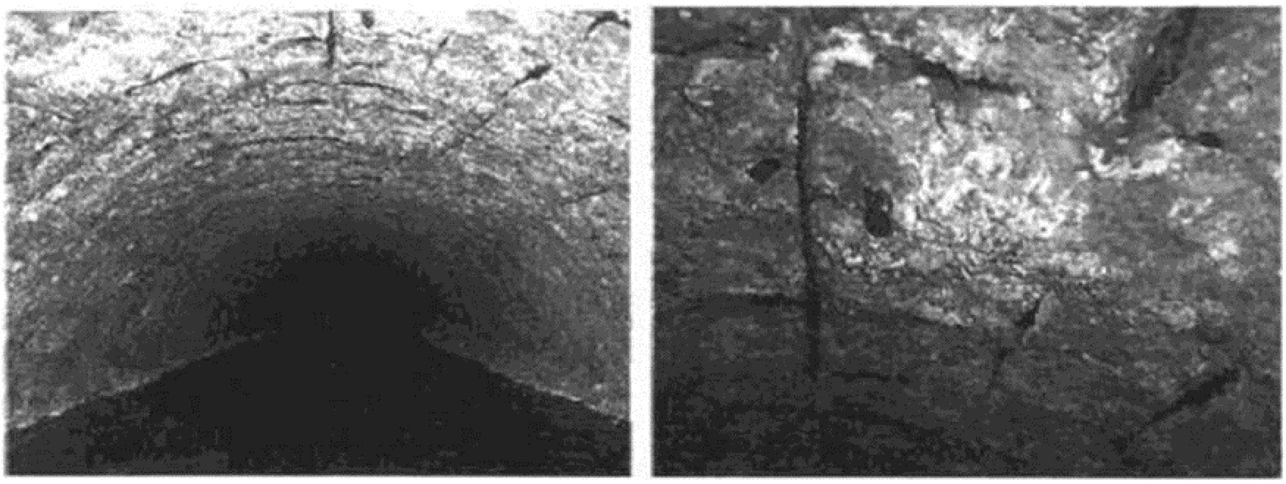

Fig. 2. Corrosion of reinforced concrete and steel reinforcement in a sewer tunnel in Kharkiv

In addition to biogenic acid attack, concrete in sewers may suffer from sulfate attack from groundwater, chloride-induced corrosion of reinforcement, abrasion by solids transported with wastewater, freeze–thaw cycles in shallow structures and impact loads during maintenance operations. Therefore, materials used in such conditions must combine chemical and biological resistance with adequate mechanical strength and crack resistance.

Classification and description of modern materials. Based on the analysis of Ukrainian and international practice [1-25], the following main groups of materials and protective systems used in sewer environments can be distinguished:

– corrosion-resistant cement concretes (including sulfate-resistant and polymer-modified concretes) [9, 22];

– polymer concretes and polymer-cement composites;

– polymer pipes (HDPE, PVC, PP);

– glass-reinforced plastic (GRP) pipes and shells;

– HDPE-lined reinforced-concrete pipes and anchored HDPE sheets;

– internal polymer protective coatings (epoxy, polyurethane and hybrid systems);

– stone and ceramic materials (granite and acid-resistant ceramics) [1-3, 6].

Corrosion-resistant cement concretes. Sulfate-resistant concretes are produced on the basis of cements with a reduced content of tricalcium aluminate and with mineral additions such as granulated blast-furnace slag, fly ash or natural pozzolans. These additions densify the microstructure, reduce the amount of free calcium hydroxide and slow down the formation of expansive ettringite. When combined with modern superplasticisers, self-compacting mixes suitable for open-cut reconstruction of collectors can be obtained.

Polymer-modified concretes incorporate polymer dispersions (styrene–acrylic, styrene–butadiene, epoxy) that partly fill capillary pores and create a polymer–cement microstructure. This leads to reduced permeability, improved crack resistance and better adhesion to polymer coatings. Such concretes are promising for the reconstruction of manholes, chambers and other structures where both load-bearing and protective functions must be combined.

Polymer concretes and polymer-cement composites. Polymer concrete uses thermosetting resins (epoxy, vinyl-ester, polyester) as a binder and mineral aggregates (granite, basalt, quartz sand). The absence of Portland cement hydration products ensures high chemical resistance and very low water absorption. Polymer concrete shows excellent performance in manholes, wet wells and sections of collectors exposed to intense biogenic corrosion and abrasion. Its main disadvantage is high material cost and strict requirements for temperature control during installation.

Polymer-cement composites with partial replacement of cement by polymer binders form an intermediate class that offers higher durability than ordinary concrete while preserving some advantages of cement systems, such as fire resistance and better behaviour at elevated temperatures.

Polymer pipes (HDPE, PVC, PP). High-density polyethylene (HDPE) pipes are widely used for external sewer networks due to their high resistance to a wide range of chemicals, immunity to electrochemical corrosion and excellent flexibility. Their smooth inner surface reduces hydraulic losses and the risk of sediment deposition. PVC and PP pipes provide high ring stiffness and are commonly used in shallow gravity sewers for residential areas. The main limitations of polymer pipes are associated with deformation under external loads at large diameters and with temperature sensitivity.

Glass-reinforced plastic (GRP) pipes and shells. GRP pipes consist of glass fibres embedded in a polymer matrix, often with a sand-filled core. They combine high corrosion resistance with high strength and relatively low weight. International experience shows that GRP pipes are effective for large-diameter trunk sewers and for trenchless rehabilitation of ageing collectors. At the same time, their application requires qualified installation and careful control of joint performance.

HDPE-lined reinforced-concrete pipes and anchored HDPE sheets. Composite systems combining a reinforced-concrete structure with a chemically inert HDPE lining are increasingly used in sewer construction. In factory-produced pipes, an HDPE liner is mechanically anchored to the concrete wall, providing full protection of the inner surface against biogenic corrosion while keeping the high load-bearing capacity of reinforced concrete. For the rehabilitation of existing collectors, anchored HDPE sheets can be installed during open-cut reconstruction. The anchors are embedded into fresh concrete, and the polyethylene surface forms a new internal lining with low roughness and high durability.

Polymer protective coatings. Thin-film coatings based on epoxy and polyurethane binders are widely used for the protection of new and existing concrete surfaces in sewer structures. When applied on a properly prepared substrate, they provide a dense, chemically resistant barrier. Modern formulations may include biocidal additives to reduce biofilm growth. The main risks are associated with inadequate surface preparation, insufficient coating thickness and mechanical damage during operation.

Stone and ceramic materials. Granite and acid-resistant ceramic tiles have traditionally been used for floors and channels at wastewater treatment plants and industrial facilities. They demonstrate high compressive strength, low water absorption and good resistance to abrasion. In sewers, such materials are mainly applied for inverts and local linings in zones with high mechanical loads, often in combination with waterproofing layers or polymer coatings.

Comparative analysis for the conditions of Kharkiv. The sewer network of Kharkiv comprises a large number of reinforced-concrete collectors of different diameters and depths, many of which have been in service for several decades. Field inspections show that the most severe damage is observed in the crown zones of trunk collectors and in manholes and chambers with intensive gas accumulation. The invert of collectors, permanently washed by wastewater, is usually in better condition (Fig. 3).

For large-diameter trunk collectors, two main strategies appear rational under Kharkiv conditions. Where open-cut reconstruction is technically possible, the existing vault can be demolished and replaced by a new vault made of corrosion-resistant self-compacting concrete, optionally combined with anchored HDPE sheets. Where open-cut works are not acceptable (dense urban development, important transport arteries), trenchless technologies using GRP or polymer pipes installed inside the existing structure can be applied.

For manholes, chambers and other point structures, corrosion-resistant concretes combined with internal polymer coatings are recommended. When constructing new facilities, it is advisable to use polymer-modified concretes with low permeability and high crack resistance, followed by application of an epoxy or polyurethane coating in the most aggressive zones.

For street and yard networks, HDPE, PVC and PP pipes are the preferred option, as they provide high corrosion resistance and ease of installation. The choice between materials should be driven by ring stiffness requirements, temperature regime and installation method (open trench vs. trenchless).

On industrial sites, including the industrial zones of Kharkiv, polymer concrete elements and granite or ceramic linings are justified in areas with high mechanical loads and aggressive wastewater. The decision should be based on a life-cycle cost analysis rather than on initial construction costs only.

Conclusions. 1. Sewer environment is characterised by a combination of chemical, biological and mechanical impacts, with biogenic sulfuric-acid corrosion being one of the key degradation mechanisms for concrete and reinforced-concrete structures.

2. Modern materials for sewer systems form several main groups: corrosion-resistant cement concretes, polymer-modified concretes, polymer concretes, polymer pipes (HDPE, PVC, PP), GRP pipes, HDPE-lined reinforced-concrete pipes and anchored HDPE sheets, polymer protective coatings and stone or ceramic materials. Each group has its own field of rational application.

3. For the conditions of the Kharkiv sewer network, a combined approach that uses both corrosion-resistant concretes and polymer materials is the most effective. Reinforced-concrete structures should primarily perform load-bearing functions, while long-term corrosion protection is ensured by polymer linings, coatings or inserts.

4. For trunk collectors, open-cut reconstruction using corrosion-resistant self-compacting concrete in combination with anchored HDPE sheets or trenchless rehabilitation using GRP or polymer pipes is recommended. For secondary networks, HDPE, PVC and PP pipes provide the best balance between durability and cost.

5. Further research for Kharkiv conditions should focus on experimental evaluation of the long-term behaviour of combined concrete–polymer systems under real sewer environments and on life-cycle cost analysis for alternative rehabilitation strategies.

a b c

d e

Fig. 3. Application of various modern materials for the rehabilitation of wastewater infrastructure facilities in the city of Kharkiv: a – Restored energy-dissipation chamber K-1 using porcelain stoneware tiles; b – Rehabilitation of a section of the sewer tunnel along Aerokosmichnyi Avenue (Kharkiv) using open-cut installation of 1500-mm CORSIS polyethylene pipes; c – Construction of an inspection shaft with wall lining using ribbed polyethylene panels; d –econstruction of the tunnel using a polyethylene vault insert; e – Rehabilitation of the inspection shaft using ribbed polyethylene; f – Lining of the inspection shaft using slag-cast panels; g – Laboratory investigation of polymer concrete at KhNUBA; h – Ceramic tile lining of the sewer manhole; i – Rehabilitation of the collector segment using profiled polyethylene lining; j – Collector rehabilitation via spiral-wound polyethylene lining

f

g

h

i

j

Fig. 3. Sheet 2

Table 1

Main groups of materials for sewer environments

No	Material group	Main advantages	Main limitations	Recommended applications
1	2	3	4	5
1	Ordinary reinforced-concrete structures	High load-bearing capacity, low cost, local availability	Low resistance to biogenic corrosion, high permeability, high maintenance needs	Existing collectors and chambers; only as a substrate for new linings
2	Sulfate-resistant and polymer-modified concretes	Improved resistance to chemical attack, reduced permeability, compatibility with traditional technologies	Higher cost than ordinary concrete, limited resistance at very low pH	New chambers and manholes; reconstruction of shallow collectors with moderate aggression

Continuation of the table 1

1	2	3	4	5
3	Polymer concretes and polymer-cement composites	Very high chemical resistance and mechanical strength, low water absorption	High material cost, strict installation conditions	Manholes and structures in highly aggressive zones; local inserts in collectors
4	HDPE, PVC and PP pipes	No corrosion, smooth inner surface, low weight, suitability for trenchless methods	Deformation sensitivity at large diameters and high cover, temperature limitations	Street and yard sewers; relining of small and medium-diameter collectors
5	GRP pipes and shells	High corrosion resistance, high strength-to-weight ratio, large available diameters	Higher cost, need for qualified installation and reliable joints	Trunk collectors and trenchless rehabilitation where open-cut is impossible
6	HDPE-lined reinforced-concrete pipes and anchored HDPE sheets	Combination of high load-bearing capacity of concrete with chemical inertness of HDPE, smooth surface	More complex production and installation, higher initial cost	New trunk collectors; open-cut reconstruction of existing collectors with preserved invert
7	Polymer protective coatings (epoxy, polyurethane)	Thin but highly resistant barrier, can be applied on existing structures	High sensitivity to surface preparation and application conditions, risk of local damage	Internal protection of chambers, manholes and local areas of collectors
8	Granite and acid-resistant ceramics	High compressive strength, low water absorption, abrasion resistance	Need for reliable waterproofing of substrate, limited performance at very low pH	Inverts and floors of treatment plants and industrial sites, local linings in sewers

References

1. Aleinikova, A. I., Sorokin, B. S., Sorokina, V. Yu. (2021). Rozrakhunok efektyvnosti vprovadzhennya monitorynhu stiykoho funktsionuvannya kompleksu kanalizatsiynykh merezh i sporud [Calculation of the efficiency of introducing monitoring of sustainable operation of sewer networks and facilities complex]. Scientific Bulletin of Construction, No. 105(3). Pp. 51–57. DOI: https://doi.org/10.29295/2311-7257-2021-105-3-51-57 [in Ukrainian].

2. Aleinikova, A., Hulievskyi, P., Voronenko, I. (2023). Orhanizatsiyno-tekhnolohichni rishennya remontu ta vidnovlennya kanalizatsiynykh tuneliv v mistsyakh mezhuvannya z ohlyadovymy shakhtamy [Organizational and technological solutions for the repair and restoration of sewage tunnels in the places adjacent to exploration mines]. Municipal utilities, No. 4 (178). Pp. 118–124. https://doi.org/10.33042/2522-1809-2023-4-178-118-124 [in Ukrainian].

3. Zabelin, S. A., Aleinikova, A. I. (2017). Suchasnyy pidkhid do doslidzhennya biohennoyi koroziyi kanalizatsiynykh kolektoriv [A modern approach to the study of biogenic corrosion of sewer

collectors]. Collected scientific works of Ukrainian state university of railway transport, No. 172. Pp. 20–36. DOI: https://doi.org/10.18664/1994-7852.172.2017.116629 [in Ukrainian].

4. Goncharenko, D., Zabelin, S., Aleinikova, A., Anishchenko, A., Hudilin, R. (2018). Development and study of a hydromechanical method for cleaning sewage collectors from contamination. Eastern-European Journal of Enterprise Technologies, No. 5(10(95). P. 40–47. DOI: https://doi.org/10.15587/1729-4061.2018.142639 [in English].

5. Goncharenko, D. F., Starkova, O. V., Aleinikova, A. I. (2014). Development of an automated system for selecting a method of water main rehabilitation using fuzzy logic. Information Processing Systems, No. 124(8). Pp. 18–23.

6. Gontscharenko, D., Aleinikova, A., Hulievskyi, P., Ratschkowskij, A. (2023). Effiziente Nutzung von Basaltelementen in Abwassernetzen. Korrespondenz Abwasser, No. 70(1). Pp. 33–35 [in German].

7. Bryhada, O. V. (2022). Ways to prevent emergencies at concrete sewer structures: monograph. Kharkiv: FOP Brovin. 132 p. [in Ukrainian].

8. Bulgakov, Yu. V. (2015). Development of organisational and technological solutions increasing operational durability of sewer tunnel collectors: PhD thesis (Tech. Sci.). Kharkiv: Kharkiv National University of Civil Engineering and Architecture (KhNUBA).

9. Goncharenko, D. F. (2008). Operation, repair and rehabilitation of sewer networks. Kharkiv: Konsum, 400 p.

10. Dobryaev, A. O., Zabelin, S. A. (2011). Technological features of constructing sewer collectors using polymer pipes. Scientific Bulletin of Construction, No. 57. Pp. 502–508.

11. Kabus, O., Lykhohrai, V. (2023). Creation of combined polymer concrete surface layer to increase the efficiency of polymer coatings in sulfuric acid environment. AIP Conference Proceedings, No. 2684(1). DOI: https://doi.org/10.1063/5.0120064. [in English].

12. Rozental, N. K. (2011). Corrosion and protection of concrete and reinforced-concrete structures of wastewater treatment facilities. Concrete and reinforced concrete, No. 2. Pp. 78–86.

13. Starkova, O. V. (2016). Modeli obgruntovanoho vyboru metodu remontu i vidnovlennya dilyanky kanalizatsiynoyi merezhi [Models for justified selection of method for repair and rehabilitation of a sewer network section]. Scientific Bulletin of Construction, No. 3 (85). Pp. 80–85. [in Ukrainian].

14. Kostyuk, T., Plugin, A., Starkova, O., Bondarenko, D., Borziak, O. (2023). Software tools for development of a methodology for selecting construction materials according to their performance characteristics. AIP Conference Proceedings, No. 2684(1). DOI: https://doi.org/10.1063/5.0120109 [in English].

15. Iurchenko, V., Lebedeva, E., Brigada. E. (2016). Environmental safety of the sewage disposal by the sewerage pipelines. Procedia Engineering, No. 134. Pp. 181–186. https://doi.org/10.1016/j.proeng.2016.01.058. [in English].

16. Iurchenko, V., Melnikova, O., Levashova, Yu., Kosenko, N. (2023). Corrosion of concrete in a water management structure in conditions of biogenic sulfuric acid aggression. Key Engineering Materials, No. 953. Pp. 55–62. https://doi.org/10.4028/p-0GBXtM. [in English].

17. Zaporozhets, V. V. (2009). Possibility of using ceramic brick and penetrating waterproofing compositions for repair and rehabilitation of inspection shafts of sewer networks. Resource-efficient materials, structures, buildings and structures, No. 18. Pp. 488–492.

18. Voronenko, V. O. (2006). Technology and organisation of repair of a sewer shaft using reinforced slag-concrete structures. Scientific Bulletin of Construction, No. 36. Pp. 35–40.

19. Stein, D. (2005). Practical Guideline for the Application of Microtunneling Methods. Germany: Stein & Partner. [in English].

20. Fischer, W. (2013). Abwasserrohre im Vergleich. KA – Wasserwirtschaft. Abwasser, No. 60(9). Pp. 765–772. [in German].

21. Kammerer, R. (2012). Schadenentwicklung in Steinzeugrohren. Korrespondenz Abwasser. No. 59(9). Pp. 812–820 [in German].

22. Pazoki, M. (2016). Comparative evaluation of polyurethane and polyvinyl chloride in lining concrete sewer pipes for preventing biological corrosion. International Journal of Environmental Research, No. 2(10). Pp. 305–312. [in English].

23. Luo, K., Zhang, S., Wang, R. (2016). Research development of tubular textile composites application on the trenchless pipeline inversion lining rehabilitation technology. Key Engineering Materials, No. 671. Pp. 306–314. [in English].

24. Hewayde, E., Nakhla, G., Allouche, E., Mohan, P. (2007). Beneficial impact of coatings on biological generation of sulfide in concrete sewer pipes. Structure and Infrastructure Engineering, No. 3(3). Pp. 267–277. DOI: https://doi.org/10.1080/15732470500424260. [in English].

25. Taheri, S., Delgado, G. P., Agbaje, O. (2020). Corrosion inhibitory effects of mullite in concrete exposed to sulfuric acid attack. Corrosion and Materials Degradation, No. 1(2). Pp. 282–295. DOI: https://doi.org/10.3390/cmd1020014. [in English].

Список використаних джерел

1. Алейнікова А. І., Сорокін Б. С., Сорокіна В. Ю. (2021). Розрахунок ефективності впровадження моніторингу стійкого функціонування комплексу каналізаційних мереж і споруд. Науковий вісник будівництва, № 105(3). С. 51–57. DOI: https://doi.org/10.29295/2311-7257-2021-105-3-51-57.

2. Алейнікова А. І., Гулєвський П. Ю., Вороненко І. В. (2023). Організаційно-технологічні рішення ремонту та відновлення каналізаційних тунелів в місцях межування з оглядовими шахтами. Комунальне господарство міст. № 4(178). С. 118–124. DOI: https://doi.org/10.33042/2522-1809-2023-4-178-118-124.

3. Забелін С. А., Алейнікова А. І. (2017). Сучасний підхід до дослідження біогенної корозії каналізаційних колекторів. Збірник наукових праць Українського державного університету залізничного транспорту, № 172. С. 20–36. DOI: https://doi.org/10.18664/1994-7852.172.2017.116629

4. Goncharenko D., Zabelin S., Aleinikova A., Anishchenko A., Hudilin R. (2018). Development and study of a hydromechanical method for cleaning sewage collectors from contamination. Eastern-European Journal of Enterprise Technologies, No. 5(10(95). P. 40–47. DOI: https://doi.org/10.15587/1729-4061.2018.142639

5. Goncharenko D. F., Starkova O. V., Aleinikova A. I. Development of an automated system for selecting a method of water main rehabilitation using fuzzy logic. Системи обробки інформації, 2014. № 124(8). С. 18–23.

6. Gontscharenko D., Aleinikova A., Hulievskyi P., Ratschkowskij A. Effiziente Nutzung von Basaltelementen in Abwassernetzen. Korrespondenz Abwasser. 2023. No. 70(1). Pp. 33–35.

7. Бригада О. В. Шляхи запобігання надзвичайним ситуаціям на бетонних спорудах водовідведення: монографія. Харків: ФОП Бровін О.В., 2022. 132 с.

8. Bulgakov Yu. V. Development of organisational and technological solutions increasing operational durability of sewer tunnel collectors: PhD thesis (Tech. Sci.). Харків: Харківський національний університет будівництва та архітектури (ХНУБА), 2015.

9. Гончаренко Д. Ф. Эксплуатация, ремонт и восстановление сетей водоотведения: монография. Харьков: Консум, 2008. 400 с.

10. Dobryaev A. O., Zabelin S. A. Technological features of constructing sewer collectors using polymer pipes. Науковий вісник будівництва, 2011. № 57. С. 502–508.

11. Kabus O., Lykhohrai V. Creation of combined polymer concrete surface layer to increase the efficiency of polymer coatings in sulfuric acid environment. AIP Conference Proceedings. 2023. No. 2684(1). DOI: https://doi.org/10.1063/5.0120064

12. Rozental N. K. Corrosion and protection of concrete and reinforced-concrete structures of wastewater treatment facilities. Beton i Zhelezobeton. 2011. No. 2. Pp. 78–86.

13. Старкова О. В. (2016). Моделі обґрунтованого вибору методу ремонту і відновлення ділянки каналізаційної мережі. Науковий вісник будівництва, № 3(85). С. 80–85.

14. Kostyuk T., Plugin A., Starkova O., Bondarenko D., Borziak O. (2023). Software tools for development of a methodology for selecting construction materials according to their performance characteristics. AIP Conference Proceedings, No. 2684(1). DOI: https://doi.org/10.1063/5.0120109

15. Iurchenko V., Lebedeva E., Brigada E. (2016). Environmental safety of the sewage disposal by the sewerage pipelines. Procedia Engineering, No. 134. Pp. 181–186. DOI: https://doi.org/10.1016/j.proeng.2016.01.058

16. Iurchenko V., Melnikova O., Levashova Yu., Kosenko N. (2023). Corrosion of concrete in a water management structure in conditions of biogenic sulfuric acid aggression. Key Engineering Materials, No. 953. Pp. 55–62. DOI: https://doi.org/10.4028/p-0GBXtM

17. Zaporozhets V. V. (2009). Possibility of using ceramic brick and penetrating waterproofing compositions for repair and rehabilitation of inspection shafts of sewer networks. Ресурсоекономні матеріали, конструкції, будівлі та споруди, № 18. С. 488–492.

18. Voronenko V. O. (2006). Technology and organisation of repair of a sewer shaft using reinforced slag-concrete structures. Науковий вісник будівництва, № 36. С. 35–40.

19. Stein D. (2005). Practical Guideline for the Application of Microtunneling Methods. Germany: Stein & Partner.

20. Fischer W. (2013). Abwasserrohre im Vergleich. KA – Wasserwirtschaft. Abwasser, No. 60(9). Pp. 765–772.

21. Kammerer R. (2012). Schadenentwicklung in Steinzeugrohren. Korrespondenz Abwasser. No. 59(9). Pp. 812–820.

22. Pazoki M. (2016). Comparative evaluation of polyurethane and polyvinyl chloride in lining concrete sewer pipes for preventing biological corrosion. International Journal of Environmental Research, No. 10(2). Pp. 305–312.

23. Luo K., Zhang S., Wang R. (2016). Research development of tubular textile composites application on the trenchless pipeline inversion lining rehabilitation technology. Key Engineering Materials. No. 671. Pp. 306–314.

24. Hewayde E., Nakhla G., Allouche E., Mohan P. (2007). Beneficial impact of coatings on biological generation of sulfide in concrete sewer pipes. Structure and Infrastructure Engineering, No. (3)3. Pp. 267–277. DOI: https://doi.org/10.1080/15732470500424260.

25. Taheri S., Delgado G. P., Agbaje O. (2020). Corrosion inhibitory effects of mullite in concrete exposed to sulfuric acid attack. Corrosion and Materials Degradation, No. 1(2). Pp. 282–295. DOI: https://doi.org/10.3390/cmd1020014.

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