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ENVIRONMENTAL EXPERTISE OF WATER TREATMENT AND WASTE MANAGEMENT SYSTEMS OF LOCAL SEWAGE FACILITIES FOR SERVICING MODERN RESIDENTIAL COMPLEXES AND RESORTS

The article presents the features and technological aspects of organizing local wastewater treatment systems, relevant and efficient equipment for mechanical and biological treatment blocks of domestic wastewater, the problem of sludge formation on mechanical screens, sand traps, and in sedimentation tanks. Toxic chemical pollutants that may be present in the sludge formed after the treatment of domestic wastewater are analyzed. The annual amount of waste generated during mechanical and biological treatment blocks of domestic wastewater at local treatment facilities is calculated. The dynamics of sludge volume increase in conditions of rising residents is shown, and waste management pathways are analyzed. Methods for separately disposing of low-organic and high-organic sludge from wastewater are discussed, integrated into the technological scheme, and recommended for use.

Keywords: *wastewater; wastewater sludge; local treatment facilities; mechanical grids; sand traps; sedimentation tanks.*

У статті показані особливості та технологічні аспекти організації локальних систем очищення стічних вод, актуальне та ефективне устаткування механічного та біологічного блоків очищення побутової стічної води, проблема утворення осаду на механічних гратах, піскоуловлювачах та у відстійниках. Проаналізовані токсичні хімічні забрудники, що можуть міститись у осадах, утворених після очищення побутових стічних вод. Розраховано річну кількість відходів, що утворюється під час механічного та біологічного блоків очищення побутових стічних вод на локальних очисних спорудах. Показано динаміку зростання кількості осадів стічних вод в умовах зростання резидентів та проаналізовано шляхи поводження із відходами. Розглянуті, введені у технологічну схему та рекомендовані до використання методики утилізації окремо низькоорганічних та високорганічних осадів стічних вод.

Ключові слова: *стічні води; осад стічних вод; локальні очисні споруди; механічні грати; піскоуловлювачі; відстійники.*

Problem's formulation

Local treatment facilities are appearing to serve residential and hotel complexes and resorts. They are used to ensure water supply and purification of household wastewater through mechanical, biological units, and disinfection units. For the biological treatment unit, closed-type aeration tanks or septic tanks are provided, where the decomposition of organic pollutants occurs. For decentralized facilities, it is logical to abandon the reagent disinfection method and instead use ozonation.

Local sewage treatment plants are being built in Ukraine under conditions that ensure environmental safety in the area where construction takes place and where the water treatment system is planned to operate. In particular, a requirement for such construction will be the absence of a risk of contaminating aquifers that are used for water supply. The issue of waste disposal is relevant both for residential complexes, where every square meter can be allocated for functional development, and for full-fledged resorts, where there is a need to ensure safety and aesthetic combination of all components of the infrastructure object. Therefore, the issue of refusing to store waste and finding resource-efficient methods of its utilization become an urgent task for the developer.

Analysis of recent research and publications

Modern conditions for the development of society and infrastructure stimulate new challenges in the field of water purification systems. Residents of industrial and urbanized cities increasingly use their own filters. In particular, membrane technologies are effective for ensuring quality drinking water and the scientists discusses filters based on metallic iron [1]. Filters based on graphene are also used for individual water purification [2]. Article [3] provides information on how ceramic water filters have been able to improve the turbidity and microbial quality of drinking water. Article [4] analyzes whether affordable ceramic water filters can improve water security in rural areas of South Africa. Article [5] provides information on rapid sand filters for removing organic micropollutants during drinking water production and their bioremediation. Among the latest solutions is the use of nanotechnology. Thus, the article [6] provides information about filters impregnated with silver nanoparticles (AgNP) that ensure the disinfection of drinking water.

An important issue is the determination of methods for the disposal of waste generated at local wastewater treatment plants. Since sewage can contain pollutants [7, 8], wastewater sludge is considered waste that requires careful analysis before selecting a disposal method. Furthermore, municipal treatment plants also have an impact on the environment. Thus, an important source of phosphates for freshwater rivers is the wastewater treatment facilities themselves [9]. In addition, wastewater sludge typically has bacteriological contamination, and the mechanism of virus inactivation in wastewater sludges is shown in [10]. The storage of sludge is strictly prohibited without special permits and conditions; they cannot be buried in regular landfills, and the requirements for sludge sites are regulated by the state standard DSTU 8727:2017 [11].

Organic waste often serves as a source of biofuel, while low-organic waste can be used for the production of building materials [12—13]. In these works, thermoplastics act as a binder for the production of building blocks. Furthermore, the authors of article [14] note that polymer fibers can be used to reinforce cement, while the authors of article [15] believe that polymers can serve as raw materials for the production of waste containers.

Evaluating the mentioned experience, the proposed methods and techniques for the disposal of wastewater sludge should be adapted, taking into account the territorial features of local treatment facilities, the chemical composition of the waste, its volumetric quantities, and providing recommendations for effective management of them.

Formulation of the study purpose

The goal of the work is to assess the water purification scheme at decentralized local treatment facilities of residential complexes, hotels, and resorts, as well as to determine the volumes of waste generated by mechanical grids, sand traps, and sedimentation tanks, and to establish a correlation between the amount of waste and the number of residents of the infrastructure object.

The work analyzes the quantitative composition of waste generated during water purification at local treatment facilities. The dynamics of the increase in wastewater treatment waste with the growth of the population occupying the living area were graphically determined in the diagrams. Considering the volumes and chemical composition of the waste, a diagram of the movement and disposal of wastewater treatment waste from local treatment facilities was constructed.

Presenting main material

In decentralized wastewater treatment conditions, mechanical treatment facilities are traditionally used. Mechanical grids are advisable to use with opening widths of 6 mm. In this case, the volume of waste per resident per year will be 16 liters/person per year, which is more than at urban wastewater treatment plants. In addition, grids with a small opening width can be used separately for processing wet sludge from anaerobic digesters. Sand and suspended solids are retained in horizontal sand traps. The amount of waste retained in the sand traps amounts to 0.02 l/person per day.

The volume of waste retained on mechanized grids and in sand traps, taking into account the total number of residents and the volume of waste per capita per year [16]. The amount of sludge retained in sedimentation tanks, taking into account the hundredth part of the average annual consumption of domestic wastewater [17], was determined by calculation. The calculations took into account the number of residents in the residential complex, hotel, or resort depending on the size of the living area. In this case, 10 m² was taken as the area convenient for one person. The determined quantities of waste retained on the grids for infrastructure facilities are shown in Fig. 1. The work includes a recalculation to the annual amount of waste, the quantities of waste retained in horizontal sand traps have been determined (Fig. 1).

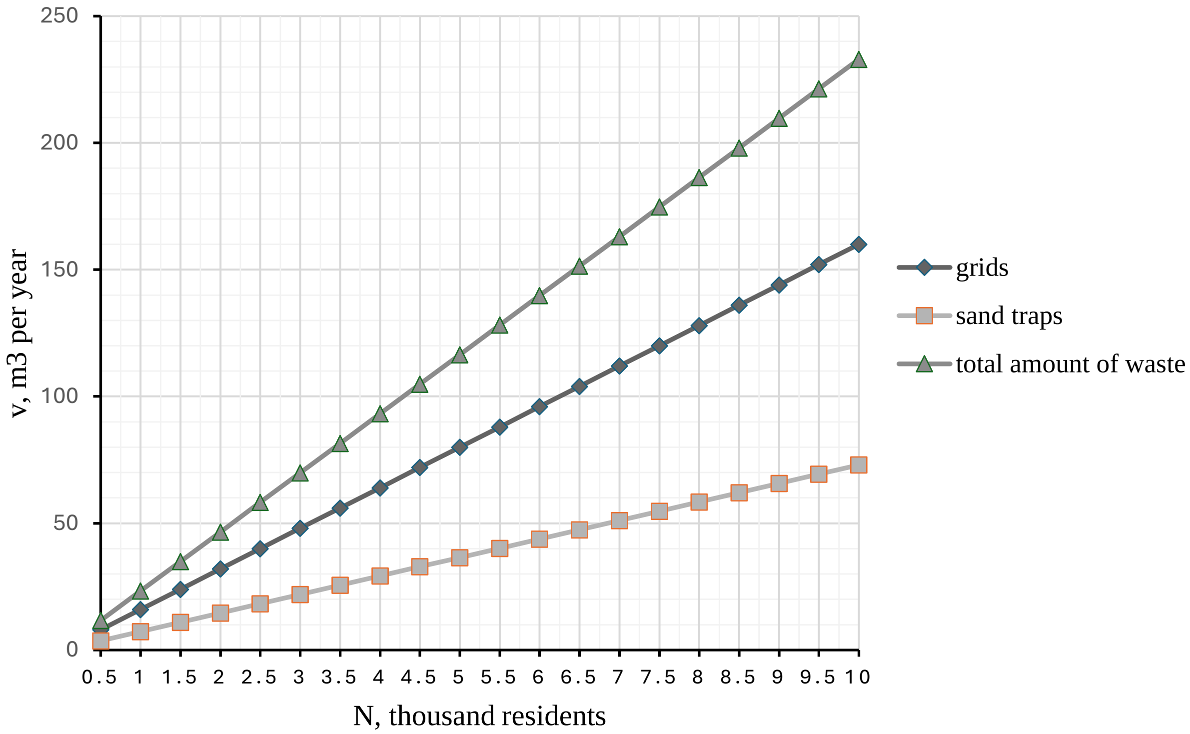

Fig. 1. Correlation between the amount of low-organic waste generated at local treatment facilities and the number of residents of the infrastructure facility.

Fig. 1 shows a direct increase in the amount of low-organic waste with the increase in the number of residents in residential complexes, hotels, and resorts. Grids retain twice as much waste as is captured in sand traps. When crushed into a powder, waste from mechanical grids along with waste from sand traps can be used in a mixture (the total amount is also shown in the graph in Fig. 1) in the construction industry as a filler in the production of building blocks.

Septic tanks or aeration tanks are used for the breakdown of organic pollutants in the context of local treatment of household wastewater. Today, closed aeration tanks, which are highly efficient, are in operation. They can be designed underground. To enhance the efficiency of separating activated sludge from water, in addition to sedimentation tanks, biofilters are provided, which typically retain activated sludge on the surface of the filtering material. Such materials may include gravel, pebbles, or layers of small-diameter plastic or ceramic material. In fact, processed thermal and formed low-organic waste from screens and sand traps can serve as the filler for the filter.

In the settling tanks, partial separation of activated sludge from residual water occurs. Often, waste in this form ends up in storage areas in sludge fields. Therefore, the quantities of this waste for different numbers of inhabitants were determined (see Fig. 2), and the dynamics of waste increase in relation to population growth were analyzed. However, organizing an area for garbage storage in a city with a high level of construction or in a recreational area covering several hectares is impractical from both economic and environmental standpoints. Therefore, measures are being taken to dewater such waste. The dynamics of the increase in the amount of waste converted to dry weight concerning the population growth in residential complexes, hotels, and resorts is shown in the graph in Fig. 2.

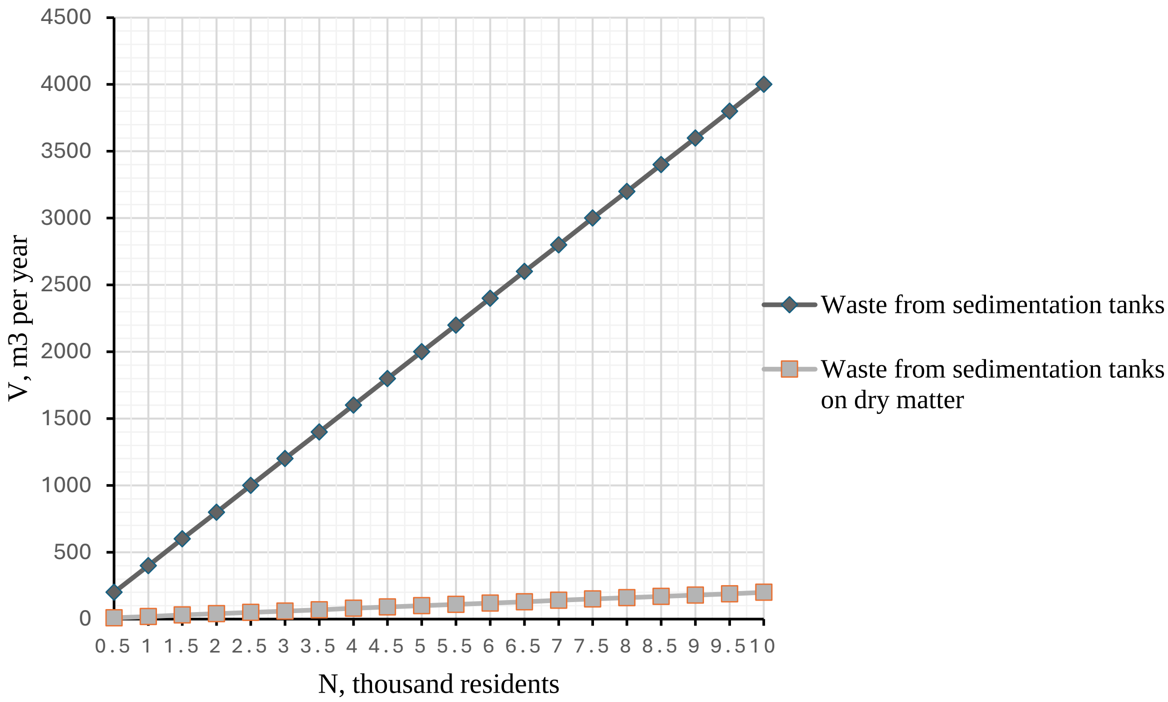

Fig. 2. Correlation between the amount of highly organic waste generated at local treatment facilities and the number of residents of the infrastructure facility.

From Fig. 2, it can be seen that the amount of waste without dehydration is several times higher than the amount of waste calculated based on dry matter.

Traditionally, the sludge from municipal wastewater treatment facilities (due to the influence of wastewater from industrial enterprises that direct their wastewater under agreements to municipal treatment facilities) can contain metal compounds, including aluminum, iron, lead, zinc, tin, cadmium, cobalt, zirconium, nickel, copper, and even vanadium, germanium, bismuth, silver, and lanthanum. Of course, in the absence of industrial wastewater at water treatment facilities, the quantitative composition of metal compounds may decrease; however, the wash water from repair and construction works, preservatives, water after rinsing cosmetic products, and wastewater after the use of household chemicals often become sources of metal compounds, nitrogen, phosphorus, potassium, and sodium.

The composition of modern food products is not always safe. Compounds such as chlorine, sodium, nitrogen, ammonium, and benzoates can be present in products that people consume daily. In particular, the preservative sodium benzoate can be found in margarine, mayonnaise, ketchup, sweet carbonated drinks, meat and fish preserves, and fruit-berry products in packaging. Sodium nitrite is an integral ingredient in boiled and semi-smoked sausages, hot dogs, and smoked meat products. The crystalline white powder ammonium chloride can be present in baked goods and pasta. The food emulsifier ammonium hydroxide may be found in confectionery products, particularly in chocolate candies, baked goods, and even in fast food.

Despite the scientific evidence proving that tartrazine can provoke allergic reactions, there are still certain discussions regarding its impact on the attention and activity of children, as it is still added to food products — confectionery, ice cream, jelly, puree, soups, yogurts, mustard, carbonated drinks, candies, and cakes. The brightly red dangerous food dye ponso may be found in sausage products, cakes, candies, canned red berries and fruits, and fillings for baked goods.

Food and cosmetic dye amaranth is also widely used in a number of countries around the world. Sodium laureth sulfate, due to its ability to form good foam, is included in a number of cleaning agents — shampoos, soaps, gels, etc. Sodium lauryl sulfate, although it can cause skin problems and oral cavity diseases (if used as a component of toothpaste), has wide applications in a number of countries around the world. Sodium and potassium hydroxides, which have an irritating effect, are contained in bar soap. Benzoic acid and methylisothiazolinone are also dangerous components of cleaning agents.

The world is gradually moving away from phosphates in laundry detergents. When they enter wastewater and are insufficiently treated at treatment facilities, these compounds become a cause for the proliferation of algae, particularly blue-green algae, which, during their life processes, reduce the oxygen content in surface water and can cause changes in the functioning and composition of ecosystems. As a result, freshwater becomes unsuitable for drinking. An alternative to phosphates is zeolites, which are gaining widespread popularity, but still have certain drawbacks. These include low washability of detergent residues from fabric, high content of anionic surfactants, and water pollution with aluminum compounds.

Traditionally for wastewater sediments, particularly those obtained from the treatment of domestic wastewater, high levels of indicators such as total microbial count and the index of lactose-positive coliform bacteria are observed. This complicates the processes of disposal and storage of such waste.

Considering the above, composting and other methods of wastewater sludge treatment, where there are no processing technologies that use high temperatures and other disinfection methods, cannot be applied even to wastewater sludge extracted from domestic sewage. Given the chemical composition of food products (which contain colorings, preservatives, flavor enhancers of chemical origin), cleaning and cosmetic products that directly affect the composition of domestic wastewater, the use of such waste as fertilizers is also hazardous. The scheme of waste formation and the specifics of their handling are shown in Fig. 3.

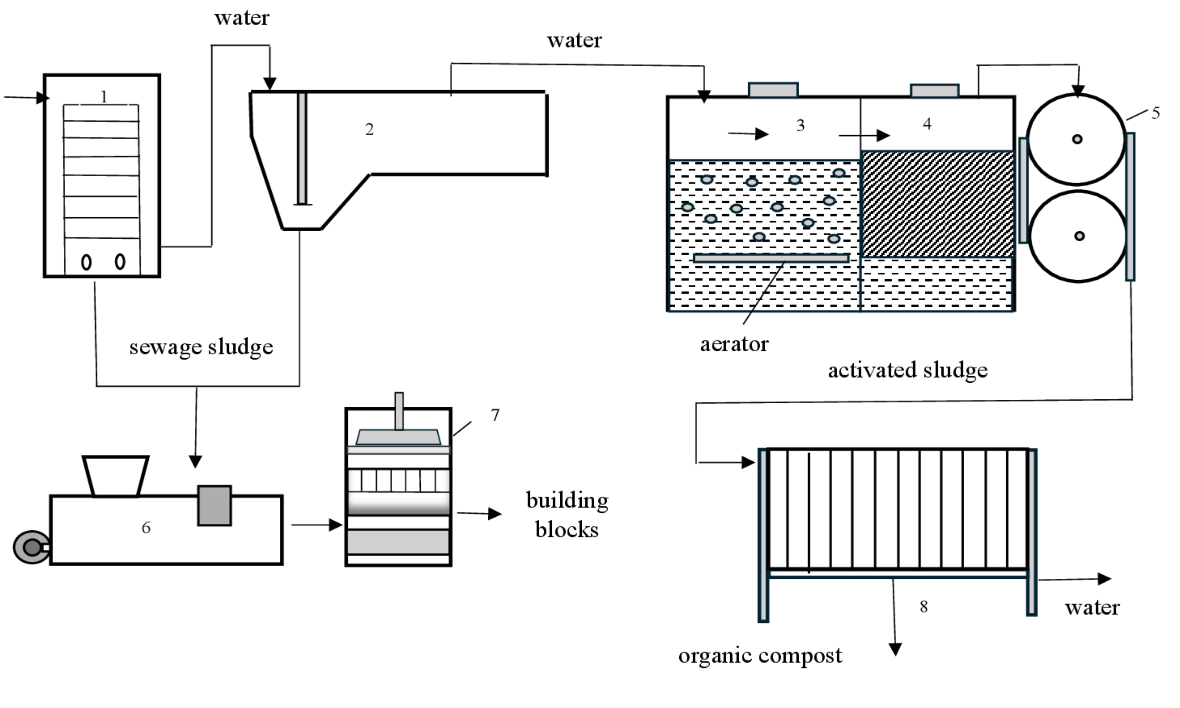

Fig. 3. Technological scheme for the movement and disposal of waste from the treatment of wastewater at local treatment facilities: 1 — mechanical grids, 2 — sand trap, 3 — aerotank, 4 — biofilter, 5 — sedimentation tanks, 6 — melting-heating unit, 7 — vibropress, 8 — filter press

Dehydrated sewage sludge can serve as a source for the production of briquettes and pellets. Without thermal treatment, dehydrated sludge should not be used as a high-organic fertilizer. Filter presses (Fig. 3) are effective for dewatering activated sludge. Considering the above, both low-organic and high-organic waste are generated at local wastewater treatment plants, depending on the equipment and technological process. The first and second can be used separately.

Fig. 3 shows that household wastewater flows from the screens to the sand traps, and then to the aeration tank, biofilter, and sedimentation tanks. Low-organic waste is formed at mechanical screens and in sand traps. Under conditions of shredding waste from mechanical screens, both types of waste are sent to the melting-heating unit. Plastic is also added to this unit (preferably of one type: polyethylene, polypropylene).

Heating occurs to the melting temperature of the selected type of plastic. The technological thermal process, besides its primary goal of binding the mixture of waste, also addresses the disinfection of the wastewater treatment waste. The viscous heated mixture goes to the vibropress, where products of specific shapes are produced. Highly organic activated sludge undergoes dewatering at the filter press and is subject to disposal or storage at sludge sites. Water after the biofilter, sedimentation tanks, and filter press goes to the disinfection stage of the wastewater from local treatment facilities.

Conclusions

When studying the correlation between the amount of low-organic waste generated at local treatment facilities and the number of residents of the infrastructure facility, it was found that mechanical grids produce significantly more waste with a predominance of inorganic components (from 8 to 160 m^3 per year, depending on the number of residents of a residential complex or resort) than in sand traps (from 3.65 to 73 m^3 per year, respectively). At the same time, the total amount of waste from mechanical grates and sand traps (from 11.65 to 233 m^3 per year, depending on the number of residents) allows for their disposal on an industrial scale. The technological scheme for processing organic-containing sediments from secondary settling tanks with the disposal of from 10 to 200 m^3 per year of dehydrated waste can also be applied on an industrial scale. The scheme of separate utilization of sewage sludge of different chemical composition allows to optimize energy and economic resources during the implementation of technological processes of heating and biological fermentation of raw materials. In addition, it allows to obtain building materials with characteristics of strength, frost resistance and water absorption that meet current national standards, as well as biofuel, which in conditions of unstable energy supply of consumers serves as an additional effective and inexpensive resource to meet thermal needs.

References

[1] Noubactep, C. (2019). Editorial for the Special Issue: Filters in Drinking Water Treatment. *Water,* 11(3). P. 522. https://doi.org/10.3390/w11030522

[2] Melucci, M., Bocchi, L., Zambianchi, M., & Palermo, V. (2025). Graphene-based filters for customized drinking water purification. Nature Water. 3(4). P. 369–371. https://doi.org/10.1038/s44221-025-00427-6

[3] Tshishonga, M., Gumbo, J.R. The Use of Ceramic Water Filters in Improving the Microbial Quality of Drinking Water. (2017). 9th Int'l Conference on Advances in Science, Engineering, Technology & Waste Management (ASETWM-17). (South Africa, 27–28 November) South Africa, 2017. P.89–91. https://doi.org/10.17758/eares.eap1117029

[4] Lange, J., Materne, T., & Grüner, J. (2016). Do low-cost ceramic water filters improve water security in rural South Africa? Drinking Water Engineering and Science, 9(2). P. 47–55. https://doi.org/10.5194/dwes-9-47-2016

[5] Timmers, P. H. A., Siegers, W., Ferreira, M. L., & van der Wielen, P. W. J. J. (2024). Bioremediation of rapid sand filters for removal of organic micropollutants during drinking water production. *Water Research*. 249. 120921. https://doi.org/10.1016/j.watres.2023.120921

[6] Rus, A., Leordean, V.-D., & Berce, P. (2017). Silver Nanoparticles (AgNP) impregnated filters in drinking water disinfection. MATEC Web of Conferences, 137. 07007. https://doi.org/10.1051/matecconf/201713707007

[7] Advances in water and wastewater treatment technology: book announcements (2001). *Journal of Soils and Sediments*, 1(3). P. 197–197. https://doi.org/10.1007/bf02986488

[8] Li, R., Wu, X., & Tang, N. (2021). Effects of effluents from wastewater treatment plants on the abiotic and biotic uptake of phosphorus by streambed sediments. Journal of Soils and Sediments. 21(10). P. 3310–3325. https://doi.org/10.1007/s11368-021-02971-6

[9] Venhauerova, P., Drahota, P., Strnad, L., & Matoušková, Š. (2021). Phosphate from treated wastewater enhances arsenic release from contaminated stream sediments. *Goldschmidt2021 Abstracts*. https://doi.org/10.7185/gold2021.7514

[10] Richard, L. W. (2019). Mechanism of Virus inactivation in Wastewater Sludges. Human Viruses in Sediments, Sludges, and Soils: CRC Press. P. 101–108. https://doi.org/10.1201/9780429270475-8

[11] Paziuk, V., & Tokarchuk, O. (2022). Main characteristics of wastewater sediments. *Engineering, energy, transport aic.* 1(116). 96–104. Internet Archive. https://doi.org/10.37128/2520-6168-2022-1-11

[12] Levytska, O., Trus, I., Gomelya, M., & Alekseyenko, S. (2022). Technology of Utilization of Polypropylene Waste and Wastewater Sediments by Production of Building Blocks. Ecological Engineering & Environmental Technology. 23(2). P. 50–59. https://doi.org/10.12912/27197050/144995

[13] Levytska, O., Dolzhenkova, O., Sichevyi, O., & Dorhanova, L. (2020). Masonry Unit Manufacturing Technology Using Polymeric Binder. *Chemistry & Chemical Technology*. 14(1). P. 88–92. https://doi.org/10.23939/chcht14.01.088

[14] Rahim, N., Salehuddin, S., Ibrahim, N. et al. (2013). Use of Plastic Waste (High Density Polyethylene) in Concrete Mixture as Aggregate Replacement. *Advanced Materials Research*. 701. P. 265 - 269. doi:10.4028/www.scientific.net/AMR.701.265

[15] Khodakarami, M., Alagha, L. (2017) High-Performance Polymers for Separation and Purification Processes: An Overview. *Polymer-Plastics Technology and Engineering.* 56. P. 2019–2042. https://doi.org/10.1080/03602559.2017.1298800

[16] Metodichni vkazivki do vikonannya kursovogo proektu, praktichnih zanyat ta samostijnoyi roboti z navchalnoyi disciplini «Vodovidvedennya (ochistka stichnih vod)» [Methodological instructions for completing a course project, practical classes and independent work on the academic discipline "Water drainage (wastewater treatment)"]: electronic edition / Kovalchuk V. A., Rivne : NUVGP, 2020. 66 p. (in Ukrainian).

[17] DBN V.2.5–75:2013. Kanalizaciya. Zovnishni merezhi ta sporudi. Osnovni polozhennya proektuvannya. [Sewerage. External networks and structures. Basic design provisions.] Kyiv: Ministry of Regional Development of Ukraine, 2023. 132 p. (in Ukrainian).

ЕКОЛОГІЧНА ЕКСПЕРТИЗА СИСТЕМ ВОДООЧИЩЕННЯ ТА ПОВОДЖЕННЯ ІЗ ВІДХОДАМИ ЛОКАЛЬНИХ КАНАЛІЗАЦІЙНИХ СПОРУД ДЛЯ ОБСЛУГОВУВАННЯ СУЧАСНИХ ЖИТЛОВИХ КОМПЛЕКСІВ ТА РЕЗОРТІВ

Реферат

Актуальною сучасною тенденцією є проєктування самостійних локальних каналізаційних споруд для очищення побутової стічної води при будівництві житлових комплексів та резортів. Авторами проведена експертна оцінка технологій очищення побутових стічних вод, що використовуються технологами і забудовниками в Україні. В даному випадку необхідно забезпечити повний цикл механічного, біологічного очищення та знезараження води від патогенних мікроорганізмів. Однією із важливих задач такого проєктування є необхідність у повній утилізації осадів стічних вод, що утворюються у піскоуловлювачах, на механічних гратах, після роботи відстійників. Це дасть можливість відмовитись від традиційних для міських очисних споруд мулових карт, котрі є джерелом забруднення ґрунтів і, що важливо в умовах щільної міської

забудови, виводять із функціональної експлуатації десятки гектарів земель. Для забезпечення ефективної утилізації відходів очищення води важливо розуміти масштаби їх утворення. Авторами визначені об'єми відходів, що утворюються при обслуговуванні від 500 до 10 тис. резидентів. Показано, що при обслуговуванні 10 тис. резидентів утвориться сумарно у механічних гратах та піскоуловлювачах більше 200 м^3 відходу, а у відстійниках — 4000 м^3 вологого осаду. Із врахуванням вмісту органічних речовин у відходах, отриманих на різних етапах очищення води, та за умов проведення експертної оцінки сучасних технологій утилізації промислових шламів і мулів, авторами запропонована схема роздільної утилізації низько- і високоорганічних осадів стічних вод із отриманням біопалива та будівельних матеріалів спеціального призначення. Вказані технологічні рішення є запорукою екологічної безпеки територій, що відведені під житлові комплекси та резорти, а також забезпечують виробництво затребуваної продукції.

Література

1. Noubactep C. Editorial for the Special Issue: Filters in Drinking Water Treatment. *Water*, 2019. 11(3). P. 522. https://doi.org/10.3390/w11030522
2. Melucci M., Bocchi L., Zambianchi M., & Palermo V. Graphene-based filters for customized drinking water purification. *Nature Water*, 2025. 3(4). P. 369–371. https://doi.org/10.1038/s44221-025-00427-6
3. Tshishonga M., Gumbo J.R. The Use of Ceramic Water Filters in Improving the Microbial Quality of Drinking Water. 9th Int'l Conference on Advances in Science, Engineering, Technology & Waste Management (ASETWM-17). (South Africa, 27–28 November) South Africa, 2017. P.89–91. https://doi.org/10.17758/eares.eap1117029
4. Lange J., Materne T., & Grüner J. Do low-cost ceramic water filters improve water security in rural South Africa? *Drinking Water Engineering and Science*, 2016. 9(2). P. 47–55. https://doi.org/10.5194/dwes-9-47-2016
5. Timmers P. H. A., Siegers W., Ferreira M. L., & van der Wielen P. W. J. J. Bioremediation of rapid sand filters for removal of organic micropollutants during drinking water production. *Water Research*, 2024. 249. 120921. https://doi.org/10.1016/j.watres.2023.120921
6. Rus A., Leordean V.-D., & Berce P. Silver Nanoparticles (AgNP) impregnated filters in drinking water disinfection. MATEC Web of Conferences, 2017. 137. 07007. https://doi.org/10.1051/matecconf/201713707007
7. Advances in water and wastewater treatment technology: book announcements. *Journal of Soils and Sediments*, 2001. 1(3). P. 197–197. https://doi.org/10.1007/bf02986488
8. Li R., Wu X., & Tang N. Effects of effluents from wastewater treatment plants on the abiotic and biotic uptake of phosphorus by streambed sediments. *Journal of Soils and Sediments*, 2021. 21(10). P. 3310–3325. https://doi.org/10.1007/s11368-021-02971-6
9. Venhauerova P., Drahota P., Strnad L., & Matoušková Š. Phosphate from treated wastewater enhances arsenic release from contaminated stream sediments. *Goldschmidt2021 Abstracts*. 2021. https://doi.org/10.7185/gold2021.7514
10. Richard L. W. Mechanism of Virus inactivation in Wastewater Sludges. Human Viruses in Sediments, Sludges, and Soils: CRC Press. 2019. P. 101–108. https://doi.org/10.1201/9780429270475-8
11. Paziuk V., & Tokarchuk O. Main characteristics of wastewater sediments. *Engineering, energy, transport aic.* 2022. 1(116). 96–104. Internet Archive. https://doi.org/10.37128/2520-6168-2022-1-11
12. Levytska O., Trus I., Gomelya M., & Alekseyenko S. Technology of Utilization of Polypropylene Waste and Wastewater Sediments by Production of Building Blocks. *Ecological Engineering & Environmental Technology*, 2022. 23(2). P. 50–59. https://doi.org/10.12912/27197050/144995
13. Levytska O., Dolzhenkova O., Sichevyi O., & Dorhanova L. Masonry Unit Manufacturing Technology Using Polymeric Binder. *Chemistry & Chemical Technology*, 2020. 14(1). P. 88–92. https://doi.org/10.23939/chcht14.01.088

14. Rahim N., Salehuddin S., Ibrahim N. et al. Use of Plastic Waste (High Density Polyethylene) in Concrete Mixture as Aggregate Replacement. *Advanced Materials Research*, 2013. 701. P. 265 - 269. doi:10.4028/www.scientific.net/AMR.701.265
15. Khodakarami M., Alagha L. High-Performance Polymers for Separation and Purification Processes: An Overview. *Polymer-Plastics Technology and Engineering*, 2017. 56. P. 2019–2042. https://doi.org/10.1080/03602559.2017.1298800
16. Методичні вказівки до виконання курсового проекту, практичних занять та самостійної роботи з навчальної дисципліни «Водовідведення (очистка стічних вод)» для здобувачів вищої освіти першого (бакалаврського) рівня за освітньо-професійною програмою спеціальності 192 «Будівництво та цивільна інженерія» (водопостачання та водовідведення) всіх форм навчання [Електронне видання] / Ковальчук В. А., Рівне : НУВГП, 2020. 66 с.
17. ДБН В.2.5–75:2013. Каналізація. Зовнішні мережі та споруди. Основні положення проектування. Київ : Мінрегіон України, 2023. 132 с.

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