DOI: https://doi.org/10.31073/mivg202501-409
Available at (PDF): https://mivg.iwpim.com.ua/index.php/mivg/article/view/409
UDC 628.5:574.8:66.098

DEWATERING OF WASTEWATER SLUDGE USING BIOFLOCCULATION

A.B. Mosiichuk, Ph.D. student

Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences,
Kyiv, 03022, Ukraine; https://orcid.org/0000-0001-9109-6746; e-mail: andrew.mosiichuk@gmail.com

Abstract. *Sludge dewatering is a crucial stage in wastewater treatment that significantly affects treatment facilities' environmental and economic efficiency. This article explores the issue of wastewater sludge dewatering using bioflocculation, a biotechnology that involves the natural process of particle aggregation involving microorganisms or their metabolites. Biological wastewater treatment remains a leading approach globally and in Ukraine; however, existing sludge dewatering methods face limitations due to high costs and insufficient efficiency. Bioflocculation helps reduce sludge moisture content, increase dry matter concentration, and decrease waste volume, contributing to resource savings and reduced chemical load. The study analyzes the impact of microbial bioflocculants on sedimentation and dewatering processes, particularly exopolysaccharides produced by Bacillus, Pseudomonas, and Klebsiella bacteria. Parameters influencing efficiency, such as dosage, contact time, pH, and aeration, are considered. Combining bioflocculation with conventional methods, such as centrifugation and mechanical thickening, enhances treatment efficiency while reducing energy and reagent consumption. Special attention is given to the potential implementation of bioflocculation at Ukrainian treatment plants, where the local production of microbial bioflocculants could replace synthetic polymers. Key influencing factors – microbial community composition, physicochemical properties of sludge, and cultivation conditions – are analyzed for their impact on process stability. The advantages of bioflocculation are outlined, including environmental friendliness, reduced product toxicity, improved dewatering, and cost reduction. At the same time, challenges such as microbial adaptation, wastewater variability, and the need for further research to implement the technology are acknowledged. Therefore, bioflocculation is a promising approach to improving wastewater treatment and sludge dewatering, aligning with modern environmental standards and supporting sustainable waste management.*

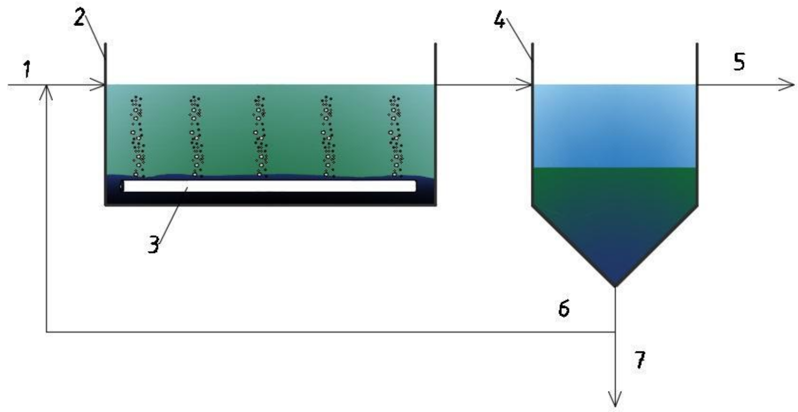
Keywords: *bioflocculation, sludge dewatering, microbial bioflocculants, activated sludge, wastewater, water treatment*

Relevance of research. Biological wastewater treatment methods are among the most widely used globally, where the core of the process is the biological oxidation of organic substances and the accumulation of inorganic compounds by living organisms [1–4]. The microbial biocenosis (a complex community of bacteria, protozoa, algae, fungi, and higher organisms) ensures the self-purification of aquatic ecosystems through metabiosis, symbiosis, and antagonism by mineralizing organic compounds that serve as sources of energy and material for biomass growth [3].

The first wastewater treatment facility using activated sludge was built in England in 1914 (Fig. 1) [5]. The core technology is based on a reactor containing an aerated suspension of microorganisms, a settling tank for separation, and a system for recirculating the sludge. Biological methods are often used with physical and chemical treatment techniques, enhancing overall efficiency.

The advantages of biological treatment include high quality and environmental friendliness; however, the lack of comprehensive theoretical models and the high dependence on personnel qualifications challenge the stable operation of treatment facilities.

A promising modern approach is bioflocculation, a natural process of particle aggregation and sedimentation facilitated by microorganisms or their metabolites. Bioflocculation promotes effective sludge dewatering, reduces operating costs, and improves the quality of treated water, which is particularly important in tightening environmental regulations. Therefore, the scientific substantiation, research, and implementation of effective biological wastewater and sludge treatment technologies remain relevant, timely, and economically advantageous tasks.



1 – water for treatment; 2 – aerotank; 3 – aeration system; 4 – settling tank; 5 – treated water; 6 – sludge recirculation; 7 – removal of excess sludge

Fig. 1. Simplified diagram of a sewage treatment plant system with activated sludge by English researchers E. Ardern and W. Lockett (1914) [6]

Analysis of recent research and publications. Bioflocculation is one of the most promising technologies for wastewater sludge dewatering, showing considerable potential for improving treatment facilities' environmental and economic performance. At the same time, current studies focus on developing and optimizing design and technological solutions for its implementation.

Ahmad et al. [7] demonstrated that the addition of exopolysaccharide-based bioflocculants increases the concentration of dry matter in sludge and significantly improves its filtration characteristics, emphasizing the development of automated bioflocculant dosing systems within secondary clarifier designs. Their results showed effective enhancement of dry matter content up to 20 %, provided uniform distribution of reagents in the working medium is achieved.

The importance of integrating bioflocculation with existing sludge dewatering technologies is highlighted in the research by Kurniawan et al. [8]. The review includes examples of mechanical thickeners, vacuum filters, and centrifuges combined with bioflocculants, which allow energy consumption to be reduced by 20–25 % and help lower operational costs by reducing the need for coagulants and chemical reagents.

Experiments conducted by Mnif and Ben Rebah [9] showed that adding *R. erythropolis* enhances the filtration properties of sludge, increasing the dry matter content to 22.5 %. They noted that the optimal operational cycle for the treatment facilities is 4–6 hours, and regular regeneration of aeration systems and mixers is essential to ensure long-term functionality.

Yu and co-authors [10] investigated the design aspects of aerotanks and sludge mineralizers adapted for bioflocculant use. They emphasized the need for regular cleaning of dosing systems to prevent clogging and maintain process stability. Additionally, they highlighted the formation of stable flocs when using biogenic *Fe(III)*, which further reduces sludge moisture.

Selepe et al. [11] investigated the effectiveness of a bioflocculant derived from *Providencia huaxiensis*, which demonstrated a flocculating activity of 90 %, indicating strong potential for industrial-scale application.

At the same time, Yang et al. [12] reported the effectiveness of the *Klebsiella sp. N-10* strain increased the dry matter content in sludge from 13.1 % to 21.3 % while reducing the specific filtration resistance. They proposed optimal technological parameters for operating treatment systems with bioflocculants:

– maintaining the dosage level within 15–40 mg/L, depending on sludge composition;

– contact time between sludge and bioflocculant ranging from 30 to 60 minutes to achieve complete particle aggregation;

– maintaining pH within the range of 6.8–7.2 to maximize polymer activity.

Peng et al. [13–20] comprehensively reviewed the potential for applying microbial flocculants with physicochemical treatment methods. They explored the effects of the combined use of bioflocculants and aluminum salts, which improved the structural stability of flocs and enhanced their dewaterability.

In Ukraine, research on bioflocculation remains mostly at the laboratory stage. For example, Klimenko and Sabliy analyzed physicochemical methods in combination with biotechnology. Still, the integration of bioflocculants into treating wastewater sludge with a high content of organic pollutants was not investigated [21–25].

Despite significant research, integrating bioflocculation into existing technological schemes requires further justification, particularly for the specific operating conditions of treatment plants in different regions.

The purpose of the research is to evaluate the effectiveness of bioflocculation as a sludge dewatering technology using microbial bioflocculants, to identify the key factors influencing process efficiency, and to justify the feasibility of its implementation at wastewater treatment plants in Ukraine.

Research materials and methods. To systematize data on bioflocculation for sewage sludge dewatering, the results of experimental studies presented in foundational works in this field were analyzed. The research methodology examined treatment systems currently in use in Ukraine, focusing on modeling potential outcomes of bioflocculation implementation. Particular attention was given to comparing the technological parameters of sludge mineralizers with the recommended conditions for bioflocculation application, specifically dosage, contact time, aeration conditions, and maintenance of optimal physicochemical parameters.

Calculations were conducted based on actual data from a potential pilot project involving bioflocculants at one of the treatment lines of a wastewater treatment facility in the Rivne region, Ukraine.

To evaluate the effectiveness of bioflocculation, the following formula was used [26]:

$$E = \frac{C_0 - C_f}{C_0} \cdot 100\,\%, \qquad (1)$$

where C_0 is the initial concentration of sewage sludge quality indicators, and C_f is the final concentration of sewage sludge quality indicators after bioflocculation.

Research results and their discussion. Bioflocculation is the process of aggregating fine dispersed particles into larger aggregates through the action of microorganisms or the biopolymers they secrete. These macromolecules form a hydrophilic matrix in which water is tightly bound, making its release from the sludge more difficult. The addition of biological flocculants leads to larger aggregates and compression of the electric double layer on particle surfaces. As a result, extracellular polymers break down, releasing bound water and enhancing sludge dewatering [9]. Charge neutralization and the formation of inter-particle "bridges" between polysaccharide chains further stabilize the flocs [12]. The primary mechanisms of bioflocculation include:

– electrostatic interactions between microorganisms and particles;

– secretion of exopolysaccharides that promote floc formation;

– hydrophobic interactions and complexation between microorganisms and pollutants.

Bioflocculants are classified into microbial flocculants (bacteria, fungi), polysaccharide-based, protein-based, and combined bioflocculants.

The main factors influencing the bioflocculation process are the composition of the microflora, the chemical makeup of the sludge (presence of organic and inorganic compounds affecting floc formation), physicochemical conditions, and the use of biopolymers.

The composition of the wastewater sludge microflora is a critically important factor influencing the bioflocculation process. Microorganisms present in sludge act as primary agents facilitating particle aggregation. Bacteria such as *Acinetobacter*, *Pseudomonas*, and *Bacillus* (see Fig. 2) and fungi like *Aspergillus* and *Penicillium* actively produce biopolymers that aid flocculation. A high concentration of exopolysaccharide-producing bacteria positively affects the formation of dense and stable flocs. Elevated metabolic activity among microorganisms enhances aggregation efficiency, as active cells more effectively interact with contaminants and promote sedimentation. The dominance of particular microorganism species can either enhance or hinder bioflocculation. For instance, some species may be less effective in producing flocculating substances or may even disrupt already-formed flocs. Microflora is sensitive to changes in pH, temperature, nutrient concentration, and toxic substances in the wastewater; optimal conditions ensure maximum activity and high-quality floc formation.

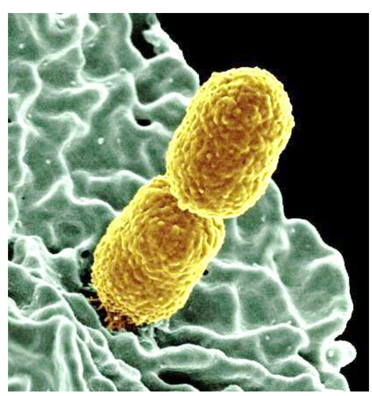


Fig. 2. Bacterial bioflocculant *Bacillus sp.*

Combining different microorganisms can form more effective bioflocculants due to the mutual enhancement of exopolymer release.

Considering these factors, the selection and optimization of the microbial composition of wastewater sludge is one of the key directions for improving the efficiency of bioflocculation. Research focused on microbial community composition and its role in aggregation processes will enable the development of new approaches to enhancing sludge dewatering technologies. For effective implementation of bioflocculation in wastewater treatment processes, the following aspects must be taken into account:

– use of activated sludge: activated sludge can serve as a source of bioflocculants to enhance sedimentation and dewatering;

– application of natural bioflocculants: using biopolymers based on exopolysaccharides to enhance coagulation and particle aggregation;

– combination with other methods: integrating bioflocculation with flotation, electrocoagulation, or ultrasonic treatment can improve treatment efficiency;

– optimization of process conditions: adjusting pH, temperature, aeration, and nutrient content to maximize bioflocculant productivity.

Bioflocculation technology can be implemented in existing aerotanks or anaerobic sludge tanks, where activated sludge already contains microorganisms capable of producing bioflocculants. Among the possible structural components of wastewater sludge dewatering technologies, activated sludge mineralizers have been identified as promising facilities for the application of bioflocculation. In mineralizers, activated sludge accumulates and stabilizes before being fed to sludge drying beds. Reducing volume and increasing dry solids concentration at this stage directly impacts subsequent dewatering and sludge disposal. Adding bioflocculants directly into mineralizers will provide the best effect, as the sludge is not yet dewatered, and the stabilization process allows for the even distribution of reagents.

Internal production of flocculants by bacteria reduces the need for expensive synthetic polymeric flocculants. It increases the environmental friendliness of the process, avoiding contamination of the sludge with heavy metals and by-products of incomplete synthesis, which are characteristic of some chemical coagulants. Considering that the synthesis of bacterial biopolymers is slower than chemical precipitation, the actual effect may appear over a more extended period than traditional coagulants.

Overall, bioflocculation can increase dry matter concentration in sludge and reduce its volume, facilitating transport and disposal. However, increased nutrient content for bacteria may promote the growth of filamentous or coliform bacteria, which can cause sludge swelling and foaming. Therefore, the production of bioflocculants and cultivation conditions (temperature, pH, nutrient availability) must be carefully controlled.

At the same time, the adaptation time for microorganisms, maintaining optimal process conditions, and potential variations in effectiveness depending on wastewater composition limit the use of bioflocculation and highlight the need for further research. Optimization of the bioflocculation process is possible by selecting effective bioflocculants by wastewater quality indicators, controlling their concentration in the system, and using mathematical models to predict process efficiency.

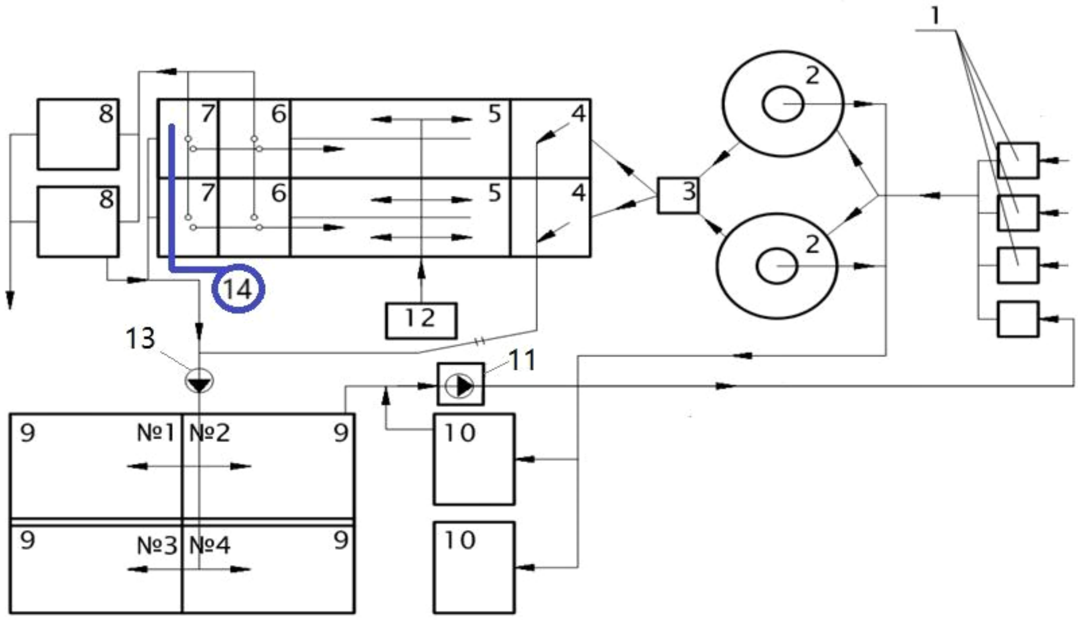
For effective implementation of bioflocculation in sludge mineralizers, it is necessary to consider the design of the mineralizer, the dosing system, regeneration process parameters, and flushing, as well as configure process parameter control.

Existing facilities should be adapted to allow for uniform dosing of bioflocculants. Dosing systems can be integrated into existing sludge feed channels, ensuring optimal flocculant concentrations (10–50 mg/L depending on sludge volume). The use of automatic dosing units ensures even distribution of reagents throughout the volume of the mineralizer. Liquid bioflocculants are preferred due to their short dissolution time and high activity.

The contact time between the sludge and the bioflocculant should be between 30 and 60 minutes. Aeration systems or mechanical stirrers are recommended to ensure uniform mixing. After each processing cycle, the mineralizer should be flushed to prevent the accumulation of residual substances. The duration of flushing should be at least 15 minutes.

Determining the optimal *pH* level (6.5–7.5), temperature (20–30 °C), and nutrient concentration is critical for the adequate performance of bioflocculants.

Considering the use of sludge mineralizers as potential facilities for the implementation of bioflocculation, the technological scheme of wastewater treatment plants will include mechanical treatment (three receiving chambers, mechanical grids, sand traps, sand drying beds, distribution chamber; radial primary clarifiers), biological treatment (two-channel aerotanks; radial secondary clarifiers; blowers; sludge pumps), wastewater disinfection (contact tanks), and sludge treatment (mineralizers; sludge drying beds with flushing drainage) (Fig. 3). To predict the effectiveness of bioflocculants at the sludge dewatering stage, sludge indicators before and after the implementation of bioflocculation are compared.



1 – Receiving chambers; 2 – Sand traps; 3 – Distribution chamber; 4 – Primary clarifiers; 5 – Aerotanks; 6 – Secondary clarifiers; 7 – Mineralizers; 8 – Contact tanks; 9 – Sludge drying beds; 10 – Sand drying beds; 11 – Drainage pumping station; 12 – Blower (air supply) pumping station; 13 – Raw sludge pumping station; 14 – Bioflocculant dosing point

Fig. 3. Predictive technological scheme of wastewater treatment facilities with sludge bioflocculation

Bioflocculants are introduced in liquid or dry form at an optimal dosage through special mixers or dosing systems to ensure uniform distribution.

The key design indicators for implementing the technology include sludge moisture content, the concentration of dry solids, the volume of dewatered sludge, and the content characteristics of heavy metals and organic matter.

Sludge moisture content (%) is calculated using the following formulas:

– without bioflocculation

$$W_1 = \frac{m_w}{m_{tot}} * 100, \qquad (2)$$

– with bioflocculation

$$W_2 = W_1 * (1 - \Delta W), \qquad (3)$$

where m_w is the mass of water in the sludge, m_{tot} is the total mass of the sludge, and ΔW is the projected decrease in moisture content.

Dry solids concentrations (%):

– without bioflocculation

$$S_1 = \frac{m_d}{m_{tot}} * 100, \qquad (4)$$

– with bioflocculation

$$S_2 = S_1 * (1 + \Delta S), \qquad (5)$$

where m_d is dry solids mass, and ΔS is the projected increase in dry solids concentration.

The volume of dewatered sludge (m³):

– without bioflocculation

$$V_1 = \frac{m_{tot}}{\rho_s}, \qquad (6)$$

– with bioflocculation

$$V_2 = V_1 * (1 - \Delta V), \qquad (7)$$

where ρ_s is sludge density, and ΔV is projected volume reduction.

Forecast of heavy metals and organic content is based on the expected reduction in toxic compounds and improved sludge stability (%):

$$C_n = C_1 * (1 - \Delta C), \qquad (8)$$

where C_n is the concentration of the n-th component, C_1 is the component without bioflocculation, and ΔC is expected to decrease in component concentration.

The calculation data is included in the predictive table.

Calculated qualitative and quantitative sludge indicators for scenarios with and without bioflocculation

Indicator	Without bioflocculation	With bioflocculation
Dry solids concentrations (%)	2–4	5–7
Sludge moisture content (%)	96–98	93–95
Sludge volume (m³/day)	250–300	200–240
Nitrogen (*N*, mg/kg)	10–15	8–12
Phosphorus (*P*, mg/kg)	20–25	18–22
Organic carbon (*C*, mg/kg)	150–200	120–180
Required sludge drying beds (m²)	1000–1200	800–1000

The projected changes in indicators demonstrate the advantages of implementing bioflocculation:

– increased concentration of dry solids (bioflocculants promote the formation of compact flocs that are easier to dewater);

– more efficient water removal reduces sludge volume and the need for sludge drying bed areas;

– the resulting flocs are more stable, decreasing the risk of rehydration and improving the overall sludge structure.

Since bioflocculation involves using microorganisms (particularly filamentous bacteria) that actively interact with suspended sludge particles, one of the key parameters for laboratory monitoring is the content of pathogenic organisms in the sludge. During the process, dense aggregates are formed in which pathogens may become mechanically encapsulated or remain free, depending on their characteristics. Filamentous bacteria create a three-dimensional matrix within the sludge structure, which can trap pathogens and restrict their access to nutrients. At the same time, anaerobic conditions develop within the flocs, which may reduce the viability of aerobic pathogens. However, such conditions may be favorable for persistent anaerobic pathogens.

If bioflocculation is effective, pathogens may be mechanically separated along with the sludge during dewatering. The formation of large, dense aggregates may also inhibit the survival of certain pathogenic microorganisms.

Conclusions. Bioflocculation is a promising method for improving the dewatering of wastewater sludge, enabling reduced environmental impact and enhanced treatment efficiency. Implementing this technology can decrease the need for chemical reagents, improve sludge processing quality, and enhance the ecological safety of wastewater treatment facilities.

To implement bioflocculation, existing sludge mineralization units must be adapted by integrating automatic dosing and process parameter control systems tailored to the specific conditions of Ukrainian treatment plants. Further research should focus on optimizing process parameters and the implementation of bioflocculants capable of functioning under a wide range of conditions. The successful application of bioflocculation may become a vital tool for sustainable water resource management in Ukraine.

References

1. California Water Plan Highlights. Department of Water Resources Bulletin 160-05. 2005.
2. Tavartkiladze, I.M., Tarasiuk, T.P., & Dotsenko, M.I. (1988). Ochisni sporudy vodovidvedennia: Dovidnyk [Sewerage treatment facilities: Reference book]. Kyiv: Budivelnyk. [in Ukrainian].
3. Kulskii, L.A. (1976). Khimiia i mikrobiolohiia vody [Chemistry and microbiology of water] [in Russian].
4. Toralova, Y., Ribarova, I., Dimkov, R., & Arsov, R. (1995) Upgrading of a small wastewater treatment plant: design & operation. *Water Sci. Tech*. Vol. 32, № 7, 111–117.
5. Water Treatment Handbook (2 Volumes set, 7th Ed.) (2007). Degrémont.
6. Mosiichuk, Ya.B. (2020). Udoskonalennia tekhnolohii ochyshchennia i vykorystannia stichnykh vod u silskii mistsevosti [Improvement of wastewater treatment and utilization technologies in rural areas] [Doctoral dissertation, Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences of Ukraine] [in Ukrainian].
7. Ahmad, J., Mohd Said, N.S., Ramli, N.N., Buhari, J., Abdullah, S.R.S., Othman, A.R., Wan Jusoh, H.H., Juahir, H., & Kurniawan, S.B. (2024). A review on the roles of extracellular polymeric substances (EPSs) in wastewater treatment: *Source, mechanism study, bioproducts, limitations, and future challenges. Water*, 16 (19), 2812. DOI: https://doi.org/10.3390/w16192812

8. Kurniawan, S.B., Abdullah, S.R.S., Imron, M.F., Said, N.S.M., Ismail, N., Hasan, H. A., Othman, A.R., & Purwanti, I.F. (2020). Challenges and Opportunities of Biocoagulant/Bioflocculant Application for Drinking Water and Wastewater Treatment and Its Potential for Sludge Recovery. *International Journal of Environmental Research and Public Health*, 17 (24), 9312. DOI: https://doi.org/10.3390/ijerph17249312

9. Mnif, W., & Ben Rebah, F. (2023). Bioflocculants as alternative to synthetic polymers to enhance wastewater sludge dewaterability: A review. Energies, 16 (8), 3392. DOI: https://doi.org/10.3390/en16083392

10. Yu, L., Tang, Q.-w., Zhang, Y.-j., Chen, R.-p., Liu, X., Qiao, W.-c., Li, W.-w., Ruan, H.-h., & Song, X. (2016). A novel Fe(III) dependent bioflocculant from Klebsiella oxytoca GS-4-08: culture conditions optimization and flocculation mechanism. *Scientific Reports*, 6 (1). https://doi.org/10.1038/srep34980

11. Selepe, T.N., Maliehe, T.S., Moganedi, K., Masoko, P., & Mulaudzi, V. (2022). Isolation and Optimisation of Culture Conditions for a Marine Bioflocculant-Producing Bacterium and Application of Its Bioflocculant in Wastewater Treatment. *International journal of environmental research and public health*, 19 (16), 10237. DOI: https://doi.org/10.3390/ijerph191610237

12. Yang, Q., Luo, K., Liao, D.-X., Li, X.-M., Wang, D.-B., Liu, X., & Xu, L. (2012). A novel bioflocculant produced by Klebsiella sp. and its application to sludge dewatering. *Water and Environment Journal*, 26 (3), 560–566. DOI: https://doi.org/10.1111/j.1747-6593.2012.00319.x

13. Peng, L., Yang, C., Zeng, G., Wang, L., Dai, C., Long, Z., Liu, H., & Zhong, Y. (2014). Characterization and application of bioflocculant prepared by Rhodococcus erythropolis using sludge and livestock wastewater as cheap culture media. *Applied microbiology and biotechnology*, 98 (15), 6847–6858. DOI: https://doi.org/10.1007/s00253-014-5725-4

14. Ntsangani, N., Okaiyeto, K., Uchechukwu, N.U., Olaniran, A.O., Mabinya, L.V., & Okoh, A.I. (2017). Bioflocculation potentials of a uronic acid-containing glycoprotein produced by Bacillus sp. AEMREG4 isolated from Tyhume River, South Africa. *3 Biotech*, 7 (1), 78. DOI: https://doi.org/10.1007/s13205-017-0695-8

15. Kurade, M.B., Murugesan, K., Selvam, A., Yu, S.M., & Wong, J.W. (2016). Sludge conditioning using biogenic flocculant produced by Acidithiobacillus ferrooxidans for enhancement in dewaterability. *Bioresource technology*, 217, 179–185. DOI: https://doi.org/10.1016/j.biortech.2016.02.113

16. Agunbiade, M.O., Van Heerden, E., Pohl, C.H. et al. Flocculating performance of a bioflocculant produced by Arthrobacter humicola in sewage waste water treatment. *BMC Biotechnol,* 17, 51 (2017). DOI: https://doi.org/10.1186/s12896-017-0375-0

17. Fujita, M., Ike, M., Tachibana, S., Kitada, G., Kim, S.-M., & Inoue, Z. (2000). Characterization of a bioflocculant produced by Citrobacter sp. TKF04 from acetic and propionic acids. *Journal of Bioscience and Bioengineering,* 89 (1), 40–46. DOI: https://doi.org/10.1016/S1389-1723 (00)88048-2

18. Dai, J., Zhao, X., Mu, S., Yang, Q., Zhao, C., & Zhao, Z. (2024). A novel polysaccharide-based bioflocculant produced by Bacillus subtilis 35A and its application in the treatment of dye decolorization, heavy metal ion adsorption and meat product wastewater. *Frontiers in Microbiology*, 15. DOI: https://doi.org/10.3389/fmicb.2024.1457909

19. Arimieari, L., & Ademiluyi, J. (2018). Sludge filtration resistance model based on electrical resistance analogy. Journal of Environmental Protection, 9, 1–12. https://doi.org/10.4236/jep.2018.91001

20. Guo, J., Liu, J., Yang, Y., Zhou, Y., Jiang, S., & Chen, C. (2018). Fermentation and kinetics characteristics of a bioflocculant from potato starch wastewater and its application. *Scientific reports*, 8 (1), 3631. DOI: https://doi.org/10.1038/s41598-018-21796-x

21. Sabliy, L.A. (2013). Fiziko-khimichne ta biolohichne ochyshchennia vysokokoncentrovanykh stichnykh vod: Monohrafiia [Physical and chemical and biological treatment of high-concentration wastewater: Monograph]. Rivne: NUVHP [in Ukrainian].

22. Koganovskii, A.M., Klimenko, N.A., Levchenko, T.M., et al. (1983). Ochistka i ispolzovanie stochnykh vod v promyshlennom vodosnabzhenii [Treatment and use of wastewater in industrial water supply]. Moskva: Khimiia [in Russian].

23. Zapolskii, A.K., Mishkova-Klimenko, N.A., Astrelin, I.A., et al. (2000). Fiziko-khimichni osnovy tekhnolohii ochyshchennia stichnykh vod [Physicochemical foundations of wastewater treatment technology] (A.K. Zapolskii, Ed.). Kyiv: Libra [in Ukrainian].

24. Klimenko, N.A., & Kozhanov, V.A. (1991). Kolloidno-khimicheskie aspekty formirovaniia sostava stochnykh vod tekstilnykh predpriiatii i vozmozhnye metody ikh ochistki [Colloidal-chemical aspects of the formation of the composition of wastewater from textile enterprises and possible treatment methods]. Khimia i tekhnologiia vody, 13 (7), 579–592. [in Russian].

25.Sabliy, L.A., & Zhukova, V.S. (2008). Vdoskonalennia roboty kanalizatsiinykh ochysnykh sporud [Improving the operation of sewer treatment facilities]. *Vodopostachannia ta vodovidvedennia*, (5), 33–36 [in Ukrainian].
26.Khoruzhii, P.D., Khomutetska, T.P., & Khoruzhii, V.P. (2008). Resursosberihaiochi tekhnolohii vodopostachannia [Resource-saving water supply technologies]. Kyiv: Ahrarna nauka [in Ukrainian].

УДК 628.5:574.8:66.098

ЗНЕВОДНЕННЯ ОСАДІВ СТІЧНИХ ВОД З ВИКОРИСТАННЯМ БІОФЛОКУЛЯЦІЇ

А.Б. Мосійчук, аспірант

Інститут водних проблем і меліорації НААН, м. Київ, 03022, Україна;
https://orcid.org/0000-0001-9109-6746; e-mail: andrew.mosiichuk@gmail.com

Анотація. *Зневоднення осадів стічних вод є важливим етапом очищення, що значно впливає на екологічність і економічність роботи очисних споруд. У статті досліджується проблема зневоднення осадів стічних вод із застосуванням біофлокуляції – біотехнології, що базується на природному процесі агрегації частинок за участі мікроорганізмів або їх метаболітів. Біологічне очищення стічних вод залишається провідним напрямом у світі та Україні, проте існуючі методи зневоднення осадів мають обмеження через високі витрати та недостатню ефективність. Біофлокуляція дозволяє знизити вологість осаду, підвищити концентрацію сухих речовин і зменшити об'єм відходів, що сприяє економії ресурсів та зменшенню хімічного навантаження. У роботі проаналізовано вплив різних мікробних біофлокулянтів, зокрема екзополісахаридів бактерій Bacillus, Pseudomonas, Klebsiella, на процеси осадження та зневоднення. Розглянуто параметри, що впливають на ефективність, зокрема дозування, час контакту, pH і аерацію. Поєднання біофлокуляції з традиційними методами, такими як центрифугування і механічне ущільнення, підвищує ефективність очищення, знижуючи споживання енергії і реагентів. Особливу увагу приділено можливостям впровадження біофлокуляції на очисних спорудах України, де внутрішнє виробництво біофлокулянтів мікроорганізмами може замінити синтетичні полімери. Проаналізовано ключові чинники – склад мікрофлори, фізико-хімічні властивості осаду, умови культивування – що впливають на стабільність процесу. Визначено переваги біофлокуляції: екологічність, зниження токсичності продуктів, покращене зневоднення і зниження витрат. Водночас відзначено виклики, пов'язані з адаптацією мікроорганізмів, варіабельністю стічних вод і потребою подальших досліджень для впровадження технології. Отже, біофлокуляція є перспективним напрямом для підвищення ефективності очищення стічних вод і зневоднення осадів, що відповідає сучасним екологічним вимогам і сприяє сталому управлінню відходами.*
Ключові слова: *біофлокуляція, зневоднення осадів, мікробні біофлокулянти, активний мул, стічні води, очищення води*