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Biosafety of marine vessels: current trends and prospects

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ABSTRACT

Background: *The global aggravation of the political situation in the world against the background of catastrophic changes in the Earth's ecology is inexorably growing. Despite the fact that most ships are equipped with Waste Water Treatment Plants (WWTP), pollution of the World Ocean remains a serious problem. One of the main reasons contributing to the pollution of the sea by ships is the lack of the ship's environmental protection equipment necessary for the work. Thus, the adoption of measures to prevent the discharge of raw sewage from ships and improve the quality of their treatment is of paramount importance.*

Materials and methods: *The data of comprehensive surveys of ship WWTP operation in the ports of Ukraine for 2009–2010 are analysed — the most intensive period of navigation in the last 20 years. To assess the quality of wastewater treatment, samples were taken for laboratory studies in accordance with the requirements of the "State Sanitary Rules and Norms for Discharge of Waste, Oily, Ballast Water and Garbage from Ships into Water Bodies", No. 199, 09/07/1997.*

Results: *The results of laboratory studies of wastewater after treatment on shipboard WWTP, conducted in the Black Sea ports of Ukraine in 2009–2010, show the unsatisfactory quality of their treatment according to the main regulated national and international indicators.*

Conclusions: *Taking into account the results of surveys of foreign ships conducted in 2009–2010, the studied literature, we consider our study worthy of serious reflection in order to understand the current situation on ships equipped with WWTP installations, determine priority areas for ensuring their efficient operation and preventing pollution of water bodies by untreated waste carrying the threat of contamination of residents of coastal areas with pathogens of dangerous infectious diseases transmitted by water, toxic substances that are detrimental to the flora and fauna of the oceans.*

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Key words: wastewater treatment plants, ships, pathogens, microorganisms, pollutants, toxicity of sea water

INTRODUCTION

Pollution of the oceans in recent decades has caused great concern to mankind. Household waste, sewage, oil products significantly limit the use of water bodies for commercial, recreational purposes by the population of coastal cities [1, 2].

A significant amount of pollutants enters coastal sea waters from ships. The main pollutants of ship wastewater are organic nitrogenous substances, which are a substrate for the development of microorganisms [3, 4].

Raw wastewater contains 5 main groups of pollutants:

— a huge number of bacteria, viruses, parasites;

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— organic and inorganic substances dissolved in water with a high biochemical oxygen demand;
— solid organic and inorganic particles settling to the bottom of reservoirs;
— floating organic and inorganic particles lingering on the surface, which makes it difficult to use the water of marine reservoirs;
— a large number of biogenic elements, leading to oversaturation and eutrophication of water bodies.

The ingress of these pollutants into water bodies leads to the rapid development of algae, disruption of the natural self-purification process, the appearance of cyanobacteria in the water that produce toxins that cause poisoning of people and animals, oxygen deficiency, and the death of fish and animals [5].

In addition, untreated sewage contains millions of pathogens that cause human infections such as gastroenteritis, cholera, hepatitis, salmonellosis, giardiasis, cryptosporidiosis, rotavirus infections, escherichiosis, leptospirosis etc. Specific diseases associated with exposure to sea water are also ear, eye, and skin diseases [6, 7].

A large group of cholerae-like vibrios to which the gram-negative bacteria Vibrio parahaemolyticus, V. mimicus, V. alginolyticus, V. hollisae and V. vulnificus belong. may cause diarrhoea, wound infection, or septicaemia. V. parahaemolyticus infections commonly occur in Japan and coastal areas of the United States.

The causative agents of these diseases can persist in sea water for an average of 2 to 20 days. This is quite enough for direct or indirect infection of a person [8].

Back in 1975–1976 in 23 states of the United States and Puerto Rico, 95 outbreaks of diseases were registered, the causative agents of which infected a person while swimming in the sea. However, there are still no accurate data on the frequency of infection among swimmers in world medical practice. Despite the fact that various diseases are constantly confirmed by the laboratory analysis of cases in coastal regions, it is impossible to establish a direct causal relationship with sea water. To date, there is not enough information on the underlying characteristics or disease levels of bathers to understand whether other factors are at play [9–11].

It is believed that people who bathe in sea water are almost twice as likely to get sick.

Vibrio vulnificus is one of the dangerous pathogens for humans. It may cause necrotising fasciitis, acute gastroenteritis, and septic shock. Vibrio vulnificus grows and reproduces in sea water at water temperatures above 20 °C. Human infection occurs when a pathogen enters an open wound from sea water or by eating insufficiently thermally processed seafood (oysters, shrimp, crabs). The largest number of cases of V. vulnificus infection was registered in the Unites States of America, Cuba, India, Brazil, Thailand, China, Japan, France, Spain, and Australia. In the United States, about 100 cases of infection are recorded annually, mainly on the coast of the Gulf of Mexico, of which an average of 35 cases end in the death of the patient [12–14].

In recent decades, cases of intoxication of people due to the consumption of fish, shellfish and other seafood from reservoirs polluted by sewage have become more frequent. The mechanisms of occurrence of toxicity of sea water underlying nonspecific syndromes have been studied [15].

The aquatic environment also plays a significant role in the spread of viral diseases. Viral and bacterial hepatitis of water origin are registered, the pathogens of which are highly resistant in the water of sea and river reservoirs, in other environmental objects [16].

A large group of parasites that cause a number of diseases dangerous to humans deserves special attention [17].

Maritime states, including Ukraine, have adopted a number of Laws and Resolutions at the international and national levels aimed at protecting the sea from pollution, formulated regulatory requirements and recommendations for wastewater treatment [18–20].

There are quite a few wastewater treatment methods, and a lot of experience has been gained in their application. All of them have certain advantages and disadvantages [21].

Currently, sea vessels are equipped with small-sized wastewater treatment plants from the world's leading manufacturers, whose operation is based on the biochemical principle of operation (about 90%). The essence of the wastewater treatment process in various modifications of installations remains unchanged, regardless of the design features: a complex of microorganisms, their metabolic products, organic and inorganic substrates form the so-called "activated sludge", in which continuous biochemical processes occur in a closed cycle [22, 23].

The operating conditions of Waste Water Treatment Plants (WWTP) on ships are significantly different from those onshore. This is due to the specific conditions on the ships: constant rolling, limited equipment dimensions, uneven flow of effluents, changes in the salinity of sea water used for discharge, contamination of the active components of the treatment plant with chemicals, fluctuations in water temperature, etc.

Under certain circumstances, the balance in the system "waste water — activated sludge" may be disturbed. Such failures lead to the exit of ship WWTPs from the passport regime and pollution of water bodies with untreated sewage. Recovery after such failures takes 20–30 days. Given the limited time that vessels spend in ports, such time delays are unacceptable. As a result, ship treatment facilities continue to operate in violation of the operating regime and discharge untreated sewage overboard [24, 25].

To date, there are various ways to intensify the process of wastewater treatment. The use of technical oxygen, oxygen-enriched air, biological oxidizers, biofilters, aeration accelerators, chemical mediators, etc. is effective. Increasing the dose of activated sludge, adding activated carbon to the mixture of activated sludge and wastewater also improves the performance of WWTP [26–28].

To clean wastewater from viruses, microbes and helminth eggs, methods are used based on a combination of coagulants and natural sorbents, lowering the pH of the water to 3.5–5.8, followed by ultraviolet irradiation, ozone treatment, and the use of various disinfectants. The use of ozone has a number of advantages over other reagents due to the ability to destroy pathogenic microorganisms, spore bacteria and viruses, deodorize and bleach wastewater [29, 30].

MATERIALS AND METHODS

MATERIALS

The authors studied numerous literature sources on the problem of morbidity among residents of coastal areas, vacationers, associated with pollution of marine and freshwater reservoirs by untreated sewage, various toxic substances, industrial discharges, pesticides and other pollutants.

The literature on the problem of protecting the World Ocean from Global pollution has been studied in terms of preserving human health, preventing the spread of dangerous human diseases through sea water when swimming, eating contaminated marine products, as well as the ongoing disappearance of many species of marine flora and fauna.

The authors studied the materials of the sanitary and epidemiological survey of 2,171 foreign ships with a crew of 44,380 people who visited the Black Sea ports of Ukraine in 2009–2010. On these ships, the WWTP ship installations were surveyed for compliance with their operational characteristics.

The results of laboratory studies of wastewater after treatment for compliance with the requirements of the "State Sanitary Rules and Norms for Discharge of Waste, Oily, Ballast Water and Garbage from Ships into Water Bodies", No. 199, 09/07/1997, MARPOL 73/78, were studied.

METHODS

All wastewater samples after treatment on ship WWTPs were taken in the presence of a chief engineer in accordance with the requirements of the "State Sanitary Rules and Norms for Discharge of Waste, Oily, Ballast Water and Garbage from Ships into Water Bodies" No. 199, 07/09/1997. The control sample of each sample was sealed in the presence of the chief engineer, sealed by the employee who conducted the sampling and the chief engineer, sealed with the ship's seal. Sampling certificates (in 2 copies) were signed by the chief engineer, the captain of the ship and, together with the control sample, remained on the ship for an independent laboratory study in case of disputes.

All samples were taken using the same methods and tested in the laboratory in accordance with the regulatory documents.

Wastewater samples taken after treatment at ship WWTPs were examined in the laboratory by bacteriological and chemical methods in accordance with the current regulatory documents governing these studies.

In accordance with the regulatory requirements for wastewater after treatment on ship WWTP, studies were carried out for indicators regulated "State Sanitary Rules and Norms for Discharge of Waste, Oily, Ballast Water and Garbage from Ships into Water Bodies", No. 199, 09/07/1997 and MARPOL 73/78: suspended substances, biological oxygen demand for 5 days, residual active chlorine (when treated with chlorine), coli-index.

There were no comments, disagreements, doubts with the results of laboratory studies, re-examination of control samples by the captains of the ships.

The results of the laboratory study of wastewater with recommendations for correcting the shortcomings were transferred to the ship's captain, chief engineer. Upon receipt of laboratory test results that did not meet the requirements of regulatory documents, penalties were applied. In the case of a short stay in the port of Ukraine, information about the results of laboratory tests was transmitted to the ship through the Maritime Agency, which was in charge of this ship.

RESULTS

Out of 2,171 foreign ships calling at the Black Sea ports of Ukraine in 2009–2010, 1,576 were equipped with WWTF (72.6 ± 0.1%), 595 were equipped with tanks for collecting raw sewage (27.4 ± 0.1%).

The sewage collection tanks had flanges for connection to onshore reception facilities. On some ships, ballast and other tanks were used to collect sewage. The use of such non-regulated tanks prevents pollution of the port water area during the stay, but leads to the discharge of sewage into the sea, at best, outside the sanitary zone. Such actions allow the ship to avoid penalties from the port authorities, but do not prevent pollution of water bodies with untreated sewage and create a threat of the spread of pathogens of infectious diseases by water, infection of residents of coastal areas, and poisoning of sea water bodies with toxic substances.

Foreign ships calling at the Black Sea ports of Ukraine in 2009–2010 were equipped with biochemical WWTP units

Table 1. Results of a laboratory study of wastewater after treatment at ship Waste Water Treatment Plants (WWTP) in the Black Sea ports of Ukraine in 2009–2010, which do not meet the requirements of "State Sanitary Rules and Norms for Discharge Waste, Oily, Ballast Water and Garbage from Ships into Water Bodies", No. 199, 09/07/1997

Laboratory study	2009			2010		
	Vessels surveyed	No. of non-standard samples	Per cent ratio	Vessels surveyed	No. of non-standard samples	Per cent ratio
Bacteriological	682	125	18.3	894	172	19.2
Chemical	682	131	19.2	894	205	22.9
Bacteriological and chemical	682	74	10.9	894	143	16.0

of various types from the respective manufacturers of environmental protection equipment. However, despite the presence of WWTP, the quality of wastewater treatment on them did not provide the final regulated result. And one of the main reasons is the human factor in the difficult operating conditions of ship's environmental protection equipment.

Sampling of wastewater after ship WWTP and laboratory studies were carried out in accordance with the unified regulatory requirements of the "State Sanitary Rules and Norms for Discharge of Waste, Oily, Ballast Water and Garbage from Ships into Water Bodies" No. 199, 09/07/1997 in accordance with the annual plan laboratory studies, taking into account the presence of ships under cargo operations in the ports of the Black Sea of Ukraine and the presence of treatment facilities on board.

Of the total number of wastewater samples taken on 1,576 foreign vessels equipped with WWTP, 414 samples did not meet the regulatory requirements (26.3 ± 0.1%). The results of a laboratory study of wastewater after ship WWTP, which do not meet the requirements of the "State Sanitary Rules and Norms for Discharge of Waste, Oily, Ballast Water and Garbage from Ships into Water Bodies" No. 199, 09/07/1997 for 2009–2010 are presented in Table 1. Of the results obtained for 2009, 125 (18.3%) samples did not meet the regulatory requirements for bacteriological indicators, 131 (19.2%) samples — for chemical indicators, 74 samples did not meet the regulatory requirements for both bacteriological and chemical indicators. Accordingly, in 2010, 172 (19.2%) samples did not meet the regulatory requirements for bacteriological indicators, 205 (22.9%) samples — for chemical indicators, 143 (16.0%) samples — for bacteriological and chemical indicators. On some ships, the samples did not meet the regulatory requirements only in terms of bacteriological indicators, on others — only in terms of chemical indicators, and on some ships — wastewater samples did not meet the regulatory requirements both in terms of bacteriological and chemical indicators at the same time. Thus, the total amount of samples that do not meet the standards includes the number of non-standard samples on some vessels only for bacteriological indicators, on others — only for chemical indicators, and on some vessels both for bacteriological and chemical indicators at the same time. As a result, the total ratio of the number of wastewater samples that do not meet regulatory requirements to the total number of samples for the period 2009–2010 amounted to 26.3%.

The results of the study were processed by the methods of correlation-regression analysis [31].

DISCUSSION

Many years of practical experience of working with sea vessels in the Black Sea ports of Ukraine, experience of working on sea vessels in voyage conditions, a large fruitful experience of interaction with ship administration, ship mechanics served as a concept for a series of studies that allow us to look at the problem of pollution of the World Ocean by discharges from ships through the eyes of specialists — physicians, epidemiologists, parasitologists, hygienists, to create the ground for interaction and cooperation with researchers on the problem of the incidence of dangerous human diseases transmitted through polluted sea water among residents of coastal regions of maritime states, the creation of algorithms for the efficient and uninterrupted operation of WWTP ship installations.

The period from 2009 to 2010 was chosen for study as the period of the most intensive shipping over the past 20 years and is no exception to the general unfavourable trend for the Ecology and Biology of the World Ocean and Humanity. The results of laboratory studies of wastewater after ship WWTP have remained at an unsatisfactory level over the past 20 years with fluctuations within 10 ± 2% of laboratory indicators that do not meet the requirements of regulatory documents and similar indicators in terms of the number of wastewater samples taken depending on the number of ships entering to the Black Sea ports of Ukraine.

Unfortunately, due to the short-term stay of ships in the ports of Ukraine under cargo operations, it is often not possible to apply penalties based on the results of a laboratory study of wastewater after treatment on shipboard

WWTP. So, for a complete laboratory study of wastewater after treatment, at least 5 days are required (for example, according to such a regulated indicator as biological oxygen demand for 5 days). As a result, one has to limit oneself to informing the captains and shipowners about certain violations on the ship through the ship's agents.

And even if other states provide for tougher sanctions for violation of environmental legislation than in Ukraine, according to the results of a laboratory study of wastewater after WWTP, which do not meet regulatory requirements, they cannot in any way compensate for the harm caused to human health by untreated wastewater, the biology of the Seas and Oceans.

CONCLUSIONS

The work of WWTP on 1,576 foreign vessels, out of 2,171 vessels that called at the Black Sea ports of Ukraine in 2009–2010, was analysed according to the main regulated indicators.

The sanitary and hygienic efficiency of various technologies of environmental protection equipment based on the combined treatment of ship wastewater has been studied.

The modes of operation of shipboard WWTPs were studied during the voyage (according to the information of senior mechanics), when moored at ports of call in order to ensure the protection of sea water bodies from biological and toxic pollution, to prevent the introduction and spread of dangerous human diseases of infectious toxic genesis, as well as the harmful effects of biological and chemical pollutants on the flora and fauna of the sea.

Analysis, hygienic assessment of the results of laboratory studies of wastewater after treatment on ships that called at the Black Sea ports of Ukraine, the study and systematisation of violations in the operation of ship WWTP confirm the need for an urgent solution to the identified problems.

The results of laboratory studies of wastewater after treatment on ship WWTP for the specified period indicate the unsatisfactory quality of wastewater treatment and the potential epidemiological, environmental and biological hazard of such ships.

Forecasting the prospects for the use of world water resources shows that while maintaining the quality of wastewater treatment at the current level, sooner or later they will be completely depleted due to the use of seawater as a diluent for discharged wastewater.

Thus, in order to prevent pollution of water bodies by untreated sewage after shipborne WWTP, which creates a constant threat of infection of the population living in coastal areas with pathogens of dangerous infectious diseases transmitted by water, poisoning of water bodies with toxic substances generated during the transformation of waste entering sea water and causing, ultimately, irreparable harm to human health, ecology and biology of the sea, it is necessary to ensure that the following initial preventive measures are implemented:

- carry out further research to improve the quality of shipboard WWTP treatment, search for more efficient methods of wastewater treatment, including the use of new biological treatment activators;
- ensure control over the timing of commissioning, the frequency of replacement of components (including preparations of microorganisms) and the uninterrupted operation of WWTP on ships;
- keep a permanent record of the regime characteristics of ship WWTP, constantly record the results of express tests of the quality of wastewater treatment in the voyage period, the results of laboratory studies of port services in ports of call;
- register all malfunctions in the WWTP operation with an analysis of the causes of violations and proposals for their elimination;
- toughen sanctions for violation of the operation of shipboard WWTPs based on the results of laboratory tests, with the accrual of damages for pollution of water bodies.

Thus, the study conducted by the authors testifies to the versatility of the problem of ship WWTP management and the difficulties that arise in their solution by the port authorities of Ukraine and other maritime states.

Measures aimed at strengthening supervision over the work of shipboard WWTPs, the search for new practical solutions to improve the quality of their work, will contribute to the prevention of water pollution during shipping, the biological improvement of not only the Black Sea basin of Ukraine, but also other areas of the World Ocean. And as a result, the measures taken will help reduce the incidence of people living and vacationing in coastal areas, dangerous infectious diseases of bacterial and viral origin, various intoxications associated with both the transformation of insufficiently treated ship effluents and disturbed biology of the flora and fauna of the seas and oceans.

Further improvement of the processes of effective treatment of ship wastewater, the search for new means of their disinfection remain relevant for hygienists, ecologists, physicians and technologists to the present.

The authors plan to further study the problem of protecting the health of residents of coastal areas of maritime states, vacationers, swimming in sea water, eating seafood contaminated with various toxic substances, pathogens of diseases dangerous to humans transmitted through sea water. Also, it is planned to prepare recommendations for residents of coastal areas, tourists bathing on the prevention of infection with dangerous diseases transmitted by water, toxic damage to the human body in areas of water use.

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REFERENCES

1. UNESCO. Facts and Figures on Marine Pollution. http://www.unesco.org/new/en/natural-sciences/ioc-oceans/focus-areas/rio-20-ocean/blueprint-for-the-future-we-want/marine-pollution/facts-and-figures-on-marine-pollution/ (Accessed December 22, 2019).
2. Depledge MH, White MP, Maycock B, et al. Time and tide. Our future health and well-being depends on the oceans. BMJ. 2019; 366: l4671, doi: 10.1136/bmj.l4671, indexed in Pubmed: 31315830.
3. Martínez ML, Intralawan A, Vázquez G, et al. The coasts of our world: Ecological, economic and social importance. Ecological Economics. 2007; 63(2-3): 254–272, doi: 10.1016/j.ecolecon.2006.10.022.
4. Johnston E, Mayer-Pinto M, Crowe T. Chemical contaminant effects on marine ecosystem functioning. J Applied Ecology. 2014; 52(1): 140–149, doi: 10.1111/1365-2664.12355.
5. Berdalet E, Fleming LE, Gowen R, et al. Marine harmful algal blooms, human health and wellbeing: challenges and opportunities in the 21st century. J Mar Biol Assoc U K. 2016; 96(1): 61–91, doi: 10.1017/S0025315415001733, indexed in Pubmed: 26692586.
6. Griffin DW, Donaldson KA, Paul JH, et al. Pathogenic human viruses in coastal waters. Clin Microbiol Rev. 2003; 16(1): 129–143, doi: 10.1128/CMR.16.1.129-143.2003, indexed in Pubmed: 12525429.
7. Wheeler B, White MP, Fleming LE. Influences of the oceans on human health and wellbeing. Seas, Society and Human Well-being Chichester, Wiley 2014: 4–22.
8. Colford JM, Wade TJ, Schiff KC, et al. Water quality indicators and the risk of illness at beaches with nonpoint sources of fecal contamination. Epidemiology. 2007; 18(1): 27–35, doi: 10.1097/01.ede.0000249425.32990.b9, indexed in Pubmed: 17149140.
9. Henrickson SE, Wong T, Allen P, et al. Marine swimming-related illness: implications for monitoring and environmental policy. Environ Health Perspect. 2001; 109(7): 645–650, doi: 10.1289/ehp.01109645, indexed in Pubmed: 11485861.
10. Griffin D, Lipp E, McLaughlin M, et al. Marine recreation and public health microbiology: quest for the ideal indicator. BioScience. 2001; 51(10): 817–825, doi: 10.1641/0006-3568(2001)051[0817:mraphm]2.0.co;2.
11. Nobles RE, Brown P, Rose J, et al. The investigation and analysis of swimming-associated illness using the fecal indicator Enterococcus in Southern Florida's marine water. Fla J Environ Health. 2000; 169: 13–19.
12. Lipp EK, Farrah SA, Rose JB. Assessment and impact of microbial fecal pollution and human enteric pathogens in a coastal community. Mar Pollut Bull. 2001; 42(4): 286–293, doi: 10.1016/s0025-326x(00)00152-1, indexed in Pubmed: 11381749.
13. Katayama H, Shimasaki A, Ohgaki S. Development of a virus concentration method and its application to detection of enterovirus and norwalk virus from coastal seawater. Appl Environ Microbiol. 2002; 68(3): 1033–1039, doi: 10.1128/AEM.68.3.1033-1039.2002, indexed in Pubmed: 11872447.
14. Simmons G, Greening G, Gao W, et al. Raw oyster consumption and outbreaks of viral gastroenteritis in New Zealand: evidence for risk to the public's health. Aust N Z J Public Health. 2001; 25(3): 234–240, doi: 10.1111/j.1467-842x.2001.tb00568.x, indexed in Pubmed: 11494991.
15. Singer H, Jaus S, Hanke I, et al. Determination of biocides and pesticides by on-line solid phase extraction coupled with mass spectrometry and their behaviour in wastewater and surface water. Environ Pollut. 2010; 158(10): 3054–3064, doi: 10.1016/j.envpol.2010.06.013, indexed in Pubmed: 20663596.
16. Nassiri R. Viruses without borders: deadly outbreaks of the 21st century. Archives Infectious Diseases Therapy. 2020; 3(1): 4, doi: 10.33140/aidt.03.01.5.
17. Bronstein AM. Parasitic human diseases: protozooses and helminthiases. Bronstein AM, Tokmalaev AK. RUDN [in Russian]. 2004. 207.
18. International Convention for the Prevention of Pollution from Ships, 1973 (International Maritime Organization). EcoLex. http://www2.ecolex.org/server2neu.php/libcat/docs/TRE/Full/En/TRE-000113.txt (2020, February 15).
19. State Sanitary Rules and Norms for Discharge Waste, Oily, Ballast water and Garbage from ships into Water Bodies, No. 199, 09.07.1997. Collection of sanitary and anti-epidemic rules and norms. Official publication in ten volumes, Kiev. [in Ukrainian]. 1999, vol. 4, part 3, p. 195-521.
20. Rules for the protection of Internal sea waters and the Territorial sea of Ukraine from pollution. Decree to the Cabinet of Ministers of Ukraine dated March 29. [in Ukrainian]. 2002, No. 431.
21. Pollution prevention equipment: under MARPOL. 2nd ed. 2006. London: IMO, 2006, p. 139. ISBN: 9789280114706.
22. Biological and Chemical Wastewater Treatment. In book Edited by Mohamed Samer, Wastewater Treatment Engineering. Published October 14th, 2015, p. 212. ISBN 978-953-51-2179-4.
23. Nagata Y. Special Issue: Microbial Degradation of Xenobiotics. Microorganisms. 2020; 8(4): 487, doi: 10.3390/microorganisms8040487, indexed in Pubmed: 32235417.
24. Pistocchi A, Andersen HR, Bertanza G, et al. Treatment of micropollutants in wastewater: Balancing effectiveness, costs and implications. Sci Total Environ. 2022; 850: 157593, doi: 10.1016/j.scitotenv.2022.157593, indexed in Pubmed: 35914591.
25. Warner W, Licha T, Nödler K. Qualitative and quantitative use of micropollutants as source and process indicators. A review. Sci Total Environ. 2019; 686: 75–89, doi: 10.1016/j.scitotenv.2019.05.385, indexed in Pubmed: 31176825.
26. Thompson KA, Shimabuku KK, Kearns JP, et al. Environmental comparison of biochar and activated carbon for tertiary wastewater treatment. Environ Sci Technol. 2016; 50(20): 11253–11262, doi: 10.1021/acs.est.6b03239, indexed in Pubmed: 27656757.
27. Bakhir VM, Panicheva SA, Prilutsky VI, et al. Electrochemical activation: inventions, systems, technology. M. 2021; 660.
28. Glibert P. Phytoplankton in the aqueous ecological theater: Changing conditions, biodiversity, and evolving ecological concepts. J Marine Res. 2019; 77(2): 83–137, doi: 10.1357/002224019828474304.
29. Margot J, Kienle C, Magnet A, et al. Treatment of micropollutants in municipal wastewater: ozone or powdered activated carbon? Sci Total Environ. 2013; 461-462: 480–498, doi: 10.1016/j.scitotenv.2013.05.034, indexed in Pubmed: 23751332.

30. Sugita H, Asai T, Hayashi K, et al. Application of ozone disinfection to remove Enterococcus seriolicida, Pasteurella piscicida, and Vibrio anguillarum from seawater. Appl Environ Microbiol. 1992; 58(12): 4072–4075, doi: 10.1128/aem.58.12.4072-4075.1992, indexed in Pubmed: 1476447.

31. Calder M, Craig C, Culley D, et al. Computational modelling for decision-making: where, why, what, who and how. R Soc Open Sci. 2018; 5(6): 172096, doi: 10.1098/rsos.172096, indexed in Pubmed: 30110442.