Охрана окружающей среды

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Perspectives of Membrane Bioreactors for Wastewater Purification from Waste of Pharmaceutical Products and Biogenic Elements

The article analyzes modern methods of wastewater treatment from bioresistant pharmaceutical products and biogenic elements. Pharmaceuticals, such as anti-inflammatory drugs, analgesics, antibiotics, narcotic drugs, hormones, drugs that reduce cholesterol, etc., are often get into sewage in small quantities. They are hardly biodegradable and, passing through wastewater treatment plants without any changes, they often end up in water bodies. They have significant negative impact on aquatic ecosystems and human health, while being present in open waters even in small quantities. Among the nutrients that are also present in the wastewater, nitrogen and phosphorus compounds deserve the greatest attention. While getting into water bodies, they cause eutrophication, which is also dangerous to ecosystems and human beings. It is shown that among modern variety of purification methods, the most suitable for removal of pharmaceutical products and biogenic elements are biochemical methods and photopurification technologies, as well as using membrane bioreactors. Biosorption-membrane methods open the possibility to use modern biotechnologies for efficient removal of bioresistant xenobiotics and reducing their negative impact on natural environment. Using photopurification technologies can help to reduce amount of nutrients discharged in surface water bodies, thus reducing their potential for eutrophication, as well as receiving additional renewable energy sources. *Bibl. 30, Fig. 3, Tab. 4.*

Key words: bioresistant pharmaceutical products, biogenic elements, biosorption-membrane purification methods, photopurification technologies, wastewater, membrane bioreactors.

Introduction

Technogenic pressure on water objects by industry and communal enterprises is an urgent issue. According to information published by UNESCO, 80 % of all diseases relate to quality of drinking water. Particular attention should be paid to water pollution with pharmaceutical products (PhP) and biogenic elements. They should be identified. Their composition, distribution, biodegradation, monitoring methods, prevention of contamination and removal of residues should be studied. Bioresistant compounds as water pollution group can be classified as xenobiotics. They are hardly biodegradable and can accumulate in the environment. Even insignificant concentrations in water (10^{-6}–10^{-9} g/l) adversely affect aquatic flora and fauna, as well as human health during water use. Biogenic elements, when they enter water bodies, lead to their eutrophication. It increases the speed of phytoplankton development on the water surface. Cyanobacteria (blue-green algae) that accumulate on the surface of the water body produce such secondary metabolites as a wide range of toxins, known as cyanotoxins. Despite the fact that they do not develop in a human body, they are considered as pathogenic organisms. It because they can potentially negatively affect human health [1].

Analysis of research and publications

Numerous studies [2–12] show very negative effects of even small amount of drugs on water objects. There are groups of drugs that are poorly soluble in water: anti-inflammatory, anesthetics, antibiotics, hormones, drugs that lower the cholesterol content. They have low biodegradability and usually pass through sewage water treatment plants without any changes. Drugstores and hospitals are widely practicing multiple diluting and discharging of injectable drugs of the 2nd and the 3rd class of danger, which have passed expire dates, into a city's sewage system. Their decomposition in the treatment facilities is about 68 %.

PhP can get in wastewaters at each phase of the lifecycle. Analysis allows drawing the conclusion [13–15] that different groups of bioresistant drugs, which are poorly soluble in water (xenobiotics), can be found in sewage. They are anti-inflammatory drugs, analgesics, antibiotics, narcotics, hormones, drugs that lower cholesterol, and so on. These substances are weakly biodegradable and, passing through the treatment plants without any changes, get into natural waters. Even in small quantities, they have a significant negative impact on water objects.

Medicines have been detected in sewage waters entering the urban sewage treatment facilities in many countries [2–18]. Medicines are removed usually inefficiently in the process of treatment and, when getting into natural water sources, they can negatively affect living organisms.

Studies also show negative effects of biogenic elements not only on flora and fauna but also on human health. Biogenic elements include carbon, nitrogen, phosphorus, potassium and others. When treating wastewater, attention is mostly paid to removal of nitrogen and phosphorus, which are associated with eutrophication of water bodies. Slowdowns and even reversibility of the eutrophication process can be achieved by stopping access of biogenic elements to the reservoirs. CO_2 is absorbed by water from the air. Therefore, it is relatively difficult to limit the concentration of carbon in water. The total productivity of water bodies is affected by the amount and nature of nitrogen and phosphorus compounds. Under favorable conditions, 1 mg of nitrogen produces 20–25 mg of algae, 1 mg of phosphorus — 40–250 mg [19]. Competent technological assessment and selection of methods for wastewater treatment for specific conditions of water management facilities should be based on knowledge of cleaning processes kinetics, as well as hydrodynamics of structures.

Phosphorus is a part of phosphates, which are used intensively while producing detergents. Phosphates are widely used in food industry and in water treatment processes. The composition of agricultural fertilizers include phosphate minerals. Phosphates are also consequences of plant and animal remains decomposition. Phosphates can enter waterbodies in a variety of ways, in particular, with domestic and industrial wastewater and can be washed out from agricultural fields. Analysis of phosphate content is an important part of integrated control of natural and drinking waters composition.

Phosphates are widely used for treating different boilers. Phosphates are added to water coolant to reduce deposits on the heat exchange surfaces. That is why an important part of boiler waters treatment is continuous control of phosphate concentration, which ensures compliance with technological norms of operation [20].

Good solubility of organophosphorus compounds in water causes an undoubted danger to the environment and human body. This is due to the ability of organophosphorus compounds to chemically bind and inactivate biological catalysts of various reactions in the body. Organophosphorus compounds possess cumulative properties in living organisms, which further enhances their toxic effects on the environment. Organophosphorus compounds are part of many so-called systemic insecticides.

Typical forms of phosphorus in municipal sewage waters are:

— orthophosphates (salts of phosphoric acids, in particular orthophosphoric acid H_3PO_4, with one phosphorus atom, for example, sodium orthophosphate Na_3PO_4) — simple molecules which are suitable for use in a biological metabolism without prior dilution;

— polyphosphates (polymers of phosphates of the general formula M-O-[P(OM)(O)-O]$_n$-M, in which M — any metal) — complex molecules with two or more phosphorus atoms, which before assimilation by organisms require preliminary hydrolysis with decomposition to orthophosphates (the process takes a lot of time);

— organic phosphates (esters of orthophosphoric acid of the general formula $(RO)_nP(O)(OH)_{3-n}$, where RO is the hydrocarbon radical.

According to [21], municipal wastewater can contain from 5 to 20 mg/dm^3 of total phosphorus (equivalent of phosphates PO_4 is from 15.7 to 62.7 mg/dm^3). Organic compounds make up from 1 to 5 mg/dm^3 out of it. The rest are inorganic compounds. Individual contribution of phosphorus to a sewerage network from one inhabitant is estimated from 0.65 to 4.80 g/day. The average value is 2.18 g/day. This contribution tends to increase due to increasing usage of detergents.

Typical forms of nitrogen in municipal wastewater are:

— nitrites — salts of nitrous acid (HNO_2);

— ammonium nitrogen (the general formula NH_4^+);

— nitrate — salts of nitric acid (HNO_3);

— nitrogen in organic compounds.

The most toxic among these compounds are nitrites, the least toxic are nitrates. Ammonium nitrogen occupies an intermediate position.

Concentration of nitrogen compounds in municipal wastewaters is not constant and depends on many factors, including the time of wastewater transportation to the treatment facilities. While transporting, organic compounds of nitrogen are mineralized to ammonium nitrogen and its content in wastewater is increasing. Nitrates and nitrites are restored to gaseous nitrogen during transportation, which is released into the atmosphere. Therefore, concentration of nitrates and nitrites decreases. During the process of wastewater treatment in aerotanks, organic nitrogen continues to mineralize into ammonia. If deep biological treatment with nitrification is applied, ammonium nitrogen is oxidized to nitrites, and then to nitrates. In this case, the concentration of ammonium nitrogen is reduced, the concentration of nitrites and nitrates increases. If deep biological treatment with nitrification and denitrification is applied, nitrates, which was

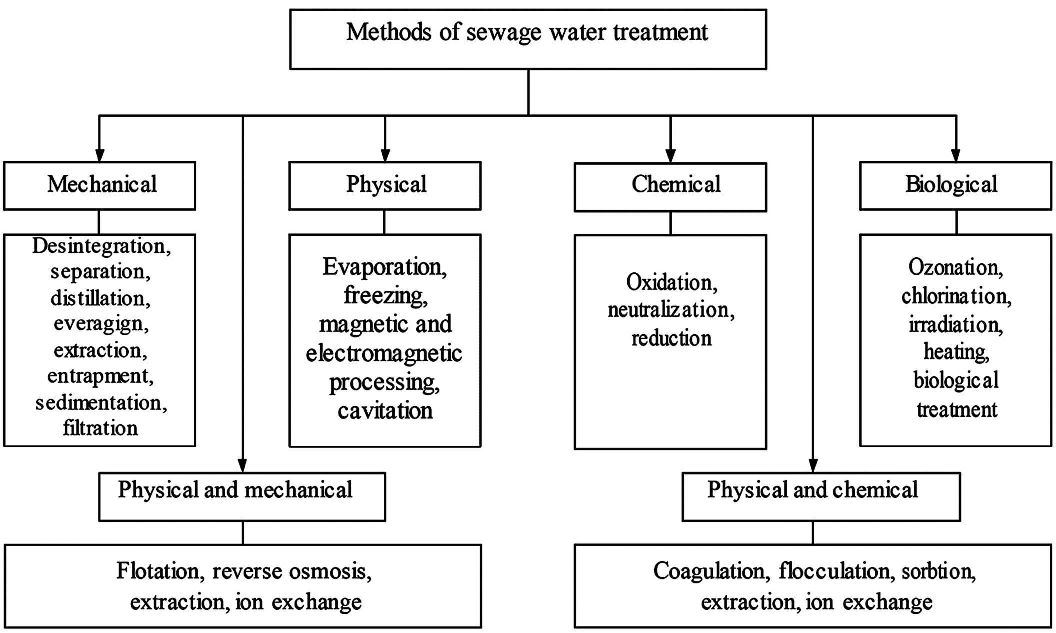

Fig. 1. Conventional classification of sewage treatment methods [24].

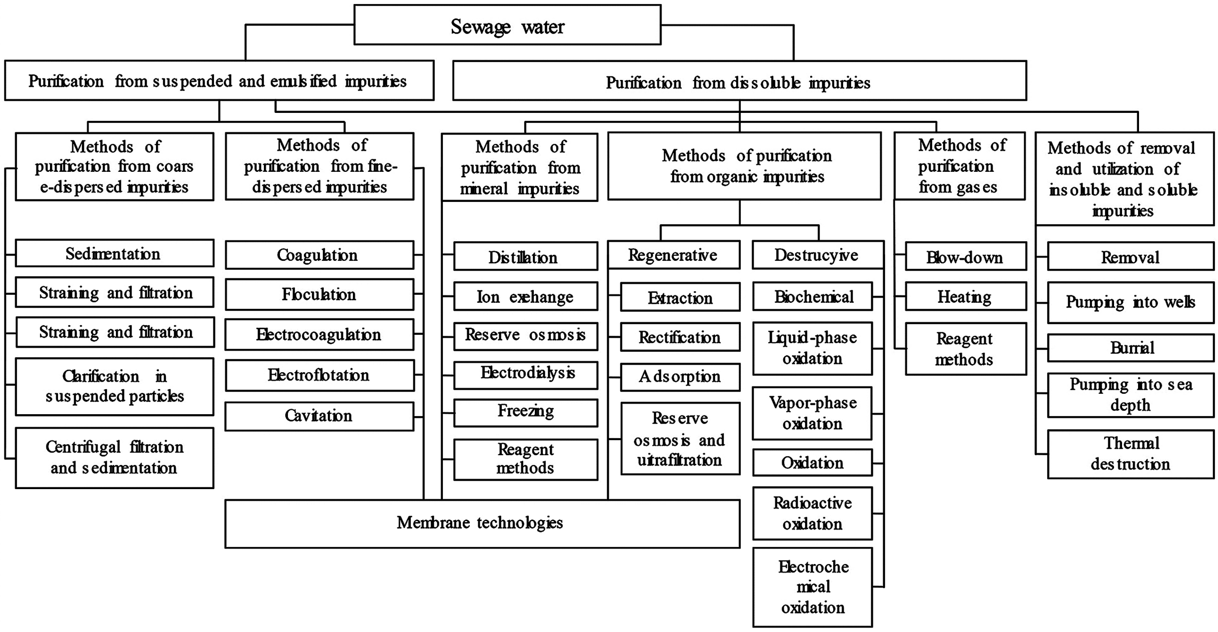

Fig. 2. Advanced classification of sewage treatment methods.

formed during nitrification, microbiologically regenerate (process of denitrification) to gaseous nitrogen. Consequently, concentration of nitrates becomes significantly reduced.

Total nitrogen content in municipal wastewater is from 50 to 60 mg/m^3 and may vary depending on the origin of the wastewater [22].

Results and discussion

Modern ways to purify wastewater vary a lot. They can be divided into mechanical, chemical, physical, biological, and their combinations. Conventional classification is presented at Figure 1. Analysis shows feasibility of biochemical methods application for purification of pharmaceutical effluents. Advanced classification of wastewater purification methods, based on recent studies, is presented at Figure 2. Comparative characteristic of sewage treatment methods is presented in Table 1. Effectiveness of biochemical purification for the most modern treatment plants is 90 % by organic matter and only 20–40 % by inorganic. If wastewater contains water contains more than 1000 mg/l of phenol, 300–500 mg/l of alcohol, 25 mg/l of petroleum products, it cannot be purified. Creation of effective biological treatment facilities and apparatus operating in such conditions is a promising direction in the technology of sewage treatment around the world. One of these facilities is membrane bioreactors (MBR) [23].

Membranes came into use in the early 1990's. Membranes are traditionally used for wastewater treatment in the next cases:

— in membrane bioreactors (which are pressurized devices or deepened membrane modules in vacuum) for separating purified wastewater from active sludge and for water after purification from suspended particles;

— while reusing waste-water and circulating water supply for removal of suspended particles and reduction of total salt content in biologically purified wastewater.

Membrane technologies can be used independently or

Table 1. Comparative characteristic of sewage treatment methods [13–19]

Treatment methods	Purification efficiency (%)			Sludge volume (% of wastewater volume)
	Suspended solid particles	Biological oxygen demand (BOD)	Bacteria	
Primary purification				
Sedimentation	40–95	30–35	40–75	0,1–0,5
Chemical sedimentation	75–95	60–80	80–90	0,5–1,0
Secondary purification				
Dripping filtration	20–80	60–90	70–85	0,1–0,5
Treatment with activated sludge	70–97	70–96	95–99	1,0–2,0

Table 2. Comparative characteristic of wastewater treatment technologies parameters based on membrane bioreactors and conventional biological treatment facilities [23]

Characteristic of purified wastewater, mg/l	Membrane bioreactors	Conventional biological treatment facilities
BOD5	< 0,4	10–30
Suspended particles	< 0,4	10–30
Turbidity	< 0,1	10–20
NH_3–N	< 0,5	< 5
Total nitrogen	< 5	< 10
Total phosphorous	< 0,2	< 1

in combination with traditional technologies. Selection of the technology should be based on the study of wastewater composition and requirements for purified water, as well as on requirements to a treatment plant performance and specific needs of each sewage. Comparative characteristic of wastewater treatment technologies parameters based on membrane bioreactors and conventional biological treatment facilities is presented in the Table 2. The table shows that membrane bioreactors provide higher level of purified wastewater quality then the quality obtained by using conventional biological treatment facilities.

At the beginning of 1990's guaranteed life time of membranes was no more than 3 years. Modern manufacturers guarantee minimum 5-year lifetime, and some of them even up to 8–10 years. One of the main characteristics of membrane technologies is the ability of membranes to remove pathogenic microorganisms from wastewater, while simultaneously disinfecting it. This is very important for pharmaceutical wastewaters. If one gram of solid household waste can contain from 0.1 to 1 billion microorganisms, pharmaceutical wastewaters can contain up to 200–300 billion of them. There can be pathogenic and bioresistent types of infections among them [23]. Table 3 and Table 4 can serve as guides for selecting a membrane technological process for different purposes.

Application of highly effective membranes is critical to effectiveness of membrane filtration technologies [23–25]. There are two main types of membrane bioreactor modules in use for water treatment plants. The first one is based on hollow fiber and the second — on flat membranes. Because of applying combined technology, membrane bioreactors combine the processes of microfiltration and ultrafiltration, as well as the process of aerobic biological treatment of wastewater (Figure 3) [11, 25]. The membranes in these reactors are not used for removing primary contaminants, but for removing biomass of activated sludge that is formed in the main capacity of the bioreactor (aerotank).

Secondary wastewater treatment (biological treatment) usually reduces phosphate content by 1–2 mg/dm^3. Nitrification is the process of oxidation of ammonium nitrogen to nitrites and nitrates with air oxygen, which is carrying out by nitrifying microorganisms. During the first stage of the nitrification ammonia is oxidized to nitrite, during the second stage — nitrites are oxidized to nitrates. The optimal pH value for nitrification process is 7–9, but the process is also possible at pH 6–7.

Denitrification is the process of reducing nitrites and nitrates to free nitrogen, which is released into the atmosphere. The process can be realized with the presence of a certain amount of organic substrate in water, which is oxidized by saprophytic microorganisms to CO_2 and H_2O with the help of oxygen of nitrogen-containing compounds. During denitrification, wastewater is purified simultaneously from biologically oxidizable organic compounds and from 12 nitrogen compounds.

Denitrification proceeds goes the most effectively at pH value from 7 to 7.5. Any biologically oxidizable organic compounds (carbohydrates, alcohols, organic acids, etc.), as well as wastewater

Table 3. Comparative characteristic of conventional wastewater treatment technologies and the latest Microza-ICBM technology

Wastewater treatment technology		Conventional	Microza МБР	
Evolution		Created in 19th century	Created at the end of 20th century	
Comparatively	Number of stages	Big	Small	
	Overall dimensions	Big	Relatively small	
	Maintenance	Laborious	Automatized	
	Purification efficiency	BOD Suspended particles Turbidity	< 15 md/l < 15 mg/l –	< 3 mg/l Not detected < 3 mg/l
Expenses		Almost the same. Microza МБР has been getting cheaper.		

Table 4. Comparative characteristic of wastewater treatment technologies for different water sources

Water source	Main characteristics	Recommended conventional treatment	Alternative membrane treatment
River	Suspended particles > 100 mg/l	Clarification + sand filtration	Microfiltration
	Suspended particles 50–100 mg/l	Clarification + sand filtration	Microfiltration or ultrafiltration
	Suspended particles < 50 mg/l	Multibed filtration	
Lake or big pond	Hard water + total organic carbon	Intensive coagulation + softening with lime + clarification + sand filtration	Intensive coagulation + microfiltration
	Suspended particles > 100 mg/l	Intensive coagulation + clarification + sand filtration	
	Suspended particles 50–100 mg/l	Coagulation + clarification + sand filtration	Microfiltration or ultrafiltration
	Suspended particles < 50 mg/l	Coagulation + sand filtration	
Artesian well	Iron + magnesium	Greensand filtration	Microfiltration
	Hardness	Filtration + softening	Microfiltration + nanofiltration
	Suspended particles > 10 mg/l	Grainy filtration	Microfiltration or ultrafiltration
	Suspended particles 5–10 mg/l		
	Suspended particles < 5 mg/l	Double cartridge filtration	
Sea	Suspended particles > 100 mg/l	Clarification + grainy filtration + desalinization	Microfiltration + reverse osmosis
	Suspended particles 50–100 mg/l	Clarification + grainy filtration + desalinization	
	Suspended particles < 50 mg/l	Doublebed filtration + desalinization	
Ultrapurified water (UPW)	Resistance 18 MOм	Mixed bed filtration	Electrodeionization
Wastewater	All wastewater characteristics	Biological treatment with activated sludge	Treatment with membrane bioreactor

after primary settling tanks, industrial effluent (preferably nitrogen-free), can be used in denitrification process as organic substrate. If this is the case, it is necessary to maintain correlation between the values of BOD and nitrates as 4 to 1.

Traditional biological treatment facilities, such as aerotanks and biofilters, can be used for the processes of nitrification and denitrification.

Denitrification of nitrate nitrogen with substrate addition. This technology involves adding into aerotanks, where processes of nitrification and denitrification take place, additional amount of organic substrate. Ethanol, methanol and acetic acid are used as the substance. The result is better efficiency of nitrites removal when the ratio of BOD to nitrogen in wastewater is inadequate. The technology can be implemented both at the stage of biological treatment and aftertreatment. It allows removal of nitrogen compounds with up to 90 % efficiency. Residual nitrogen is obtained mainly in the least toxic form — the form of nitrates. Content of ammonium and nitrite forms is minimized. The technology is expensive because of its high operating costs. It is also hazardous to maintenance personnel (methanol and acetic acid are hazardous substances).

Anaerobic ammonium oxidation (ANAMMOX). Half of the ammonium, which is contained in wastewater, is oxidized to nitrite during the process of biological nitriding in the first reactor. The second half is oxidized by nitrite formed in the second reactor under anaerobic conditions. It is also possible to apply simul-

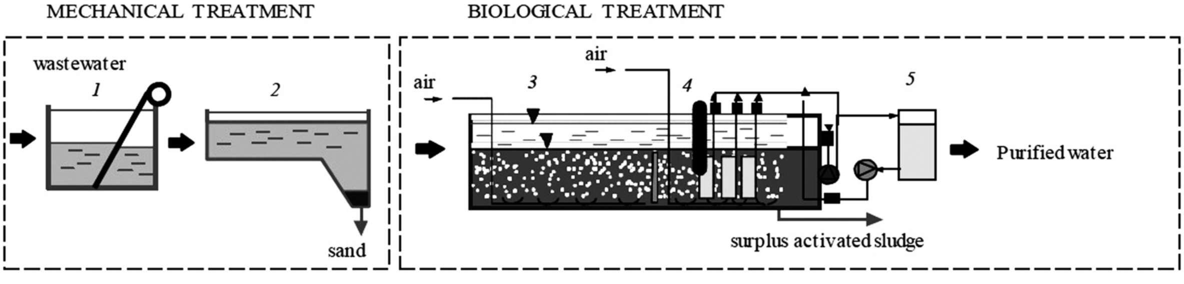

Fig. 3. Generalized scheme of membrane wastewater purification: 1 — screen; 2 — sand catcher; 3 — aerotank; 4 — membrane filtration block; 5 — capacity for purified wastewater.

taneous technology, when both processes take place in the same reactor. It increases nitrogen removal efficiency and reduces greenhouse gases emission (CO_2 is consumed during the process). The technology has low energy consumption, produces little sediment and does not depend on sources of organic substances for denitrification. However, technology requires high-quality maintenance personnel.

Biosorption aftertreatment. The technology is a combination of wastewater purification with activated sludge and powdered activated carbon (PAC). The PAC is added into aerotanks in amounts that can be extracted from the wastewater with excess activated sludge. Sorption of difficult-to-oxidize contaminants take place on the surface of PAC with their subsequent oxidation. High efficiency of organic and nitrous contamination removal can be achieved. Characteristics of purified wastewater can be: chemical oxygen demand (COD) — less than 10 mg/dm^3; BOD5 — less than 3 mg/dm^3; total nitrogen — less than 1 mg/dm^3; ammonia nitrogen — less than 0,2 mg/dm^3.

Another type of technology involves adding of fluidized bed loading in the form of granular activated carbon (GAC) instead of PAC. Advantage of the technology is longer useful life of GAC and, consequently, less amount of waste formed. However, the technology is expensive because of high cost of activated carbon.

Sorption aftertreatment with activated carbon. The technology involves filtration of wastewaters through filters of various designs filled with GAC. Sorption of organic contaminants and ammonia nitrogen take place there. The technology provides COD reducing to 5–15 mg/dm^3, BOD5 — less than 3 mg/dm^3, ammonia nitrogen — less than 1 mg/dm^3. However, a lot of waste is generated as a result (used GAC).

Sorption aftertreatment with mineral sorbents. Wastewater is filtered through filters of various designs, loaded with mineral sorbents. Different types of zeolites, including chemically modified, modified clays, are used as sorbents. The result is organic contaminants and ammonia nitrogen removal. It is possible to achieve the following wastewater characteristics: COD — 5–15 mg/dm^3; BOD5 — less than 3 mg/dm^3; ammonia nitrogen — less than 1 mg/dm^3. Technology requires applying additional facilities. The problem is the necessity to purify regenerative water generated during the regeneration of sorbents.

Aftertreatment in bioponds. The technology involves putting treated wastewater into open-air reservoirs or water bodies and keeping it there from a few days to 1–2 weeks. Mainly bacteria, similar to purification in aerotanks, do purification. Removal of biogenic elements is due to the growth of biomass of water plants. Aftertreatment allows reducing suspended particles content to 10 mg/dm^3. It allows reducing ammonium nitrogen content to 2 mg/dm^3, BOD5 to 5 mg/dm^3. In the presence of higher aquatic plants, there is a significant reduction in the content of nitrogen and phosphorus.

Ultrafiltration. Wastewater goes under pressure through a semipermeable membrane. As a result, there is separation of filtrate (purified water) and concentrate (concentrated solution of contaminants). Ultrafiltration membranes with a pore size of 0.1–0.01 мm are used. The result is efficient removal of suspended particles, colloidal particles, bacteria, viruses, and the like. When using reagents, efficient phosphate removal is possible. Technology is expensive and requires a lot of energy input.

Photopurification technologies. Photopurification systems (PPS) are divided into systems with open water surface (open bioponds with higher aquatic vegetation) and systems with subsurface water flow (closed structures of the hydroponic type). Organic compounds are decomposed in aerobic and anaerobic conditions with the help of bacteria, which develop on underwater or underground parts of aquatic plants, as well as on the surface of mineral loading. Nitrogen removal take place due to such processes as nitrification, denitrification, ANAMMOX, assimilation by plants (during the period of their biomass growth). Phosphorus is removed due to exchange-sorption reactions on the surface of mineral loading by formation of insoluble or slightly soluble salts. PPS can provide efficient purification of wastewater without requiring electricity, reagents or complex equipment. There are no wastes also. All PPS require large areas. In addition, at temperatures of 3–5 °C all biological processes are slowed down significantly. Under such conditions, these structures operate with significantly lower efficiency.

Aftertreatment with microalgae. Microalgae are good absorbers of biogenic elements. They use nitrogen and phosphorus compounds in the process of photosynthesis. Consequently, microalgae can be used purifying wastewater primarily from biogenic elements. Thus, it is possible to reduce the risks of eutrophication development in open water bodies when discharging treated wastewater.

Microalgae are an effective solar energy converter, capable of restoring carbon dioxide to a range of complex energy-intensive molecules such as hydrocarbons, proteins, lipids. It allows them to be used for further production of biodiesel, biobutanol, bioethanol, hydrogen, biogas, vitamins, antioxidants, amino acids, etc. [26–29]. Biomass of algae can be successfully used for the production of semi-finished products, with following synthesis of biodegradable polymers out from them.

It is possible to get different contents of hydrocarbons, proteins and lipids in biomass of microalgae by changing the conditions of their cultivation [30]. To do this, it is necessary to provide optimal cultivation parameters for the selected microalgal culture, such as initial concentration of cells in sewage, intensity of illumination, ambient temperature, etc. By changing these parameters, it is possible to cultivate biomass of different biochemical composition.

Conclusions

Based on this research a conclusion can be drown that prospects of wastewater purification from bioresistant PhP and biogenic elements are as follows:

1. Among the variety of existing wastewater treatment methods, such as mechanical, chemical, physical and chemical, biological purification is cha racterized by the highest efficiency (up to 99 %).

2. Taking into account complexity of PhP biodegradation, biosorption-membrane methods give the possibility of efficient use of modern biotechnologies in the field of wastewater treatment and efficient removal of bioresistant xenobiotics of anthropogenic nature during wastewater treatment.

3. Since the pore of membranes are smaller than the size of microorganism's cells, there take place partial disinfection of wastewater in MBR. Bacterial and viral removal efficiency is about 99 %.

4. Due to the fact that the pore size of ultra- and microfiltration membranes is several times smaller than the size of cells of activated sludge, it is impossible for it to end up in filtered water. This is a significant operational difference from secondary sedimentation, where present of sludge in treated water is a problem of exploitation.

5. Using MBR in technological schemes of water treatment can significantly reduce reagents amount. It can also allow refusing application of deep purification phase to remove bioresistant xenobiotics of anthropogenic nature.

6. Application of photopurification technologies with microalgae cultivation can reduce discharges of biogenic elements in surface water bodies, thereby reducing their potential for eutrophication. It also can help to obtain additional renewable energy sources, primarily in the form of biodiesel and biomass, made from microalgae.

The prospects of microbiological methods of wastewater purification from bioresistant PhP are quite optimistic and well grounded. For purification of water from this kind of xeobiotics, there is a more promising way of combining microbiological and membrane methods. For wastewater purification from biogenic elements, it is promising to use photopurification technologies with microalgae cultivation.

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Перспективи мембранних біореакторів для очищення стічних вод від відходів фармацевтичних продуктів та біогенних елементів

Проаналізовано сучасні методи очищення стічних вод від біорезистентних фармацевтичних препаратів та біогенних елементів. Фармацевтичні препарати протизапальні, знеболюючі, антибіотики, наркотичні засоби, гормони, ліки для зниження вмісту холестерину тощо часто у незначних кількостях виявляються у стічних водах. Вони слабо піддаються біодеструкції та, проходячи через очисні споруди без змін, потрапляють у водні об'єкти. у стічних водах, на найбільшу увагу заслуговують сполуки азоту та фосфору. Потрапляючи у водні об'єкти, вони спричиняють ев потрапляють у водні об'єкти. Навіть у невеликих кількостях вони можуть здійснювати суттєвий негативний вплив на водні екосисекосистеми та на здоров'я людини. Серед біогенних елементів, які також присутні у стічних водах, на найбільшу увагу заслуговують сполуки азоту та фосфору. Потрапляючи у водні об'єкти, вони спричиняють евтрофікацію, що також є небезпечною для екосистем та людини. Показано, що серед сучасного різноманіття методів очищення стічних вод найбільш придатними для видалення фармацевтичних препаратів та біогенних елементів є біохімічні методи та фотоочисні технології, а також використання мембранних біореакторів. Біосорбційно-мембранні методи уможливлюють ефективного використання сучасних біотехнологій глибокого видалення біорезистентних ксенобіотиків та зменшення їх негативного впливу на довкілля. Застосування фотоочисних технологій дає можливість зменшити скиди біогенних елементів у поверхневі водойми та тим самим зменшити їх потенціал евтрофікації, а також отримувати додаткові відновлювані джерела енергії. *Бібл. 30, рис. 3, табл. 4.*

Ключові слова: біорезистентні фармацевтичні препарати, біогенні елементи, біосорбційно-мембранні методи очищення, фотоочисні технології, стічні води, мембранні біореактори.

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Перспективы мембранных биореакторов для очистки сточных вод от отходов фармацевтических препаратов и биогенных элементов

Проанализированы современные методы очистки сточных вод от биорезистентных фармацевтических препаратов и биогенных элементов. Фармацевтические препараты противовоспалительные, обезболивающие, антибиотики, наркотические средства, гормоны, лекарства для снижения содержания холестерина и другие часто в небольших количествах присутствуют в сточных водах. Они слабо поддаются деструкции и, проходя через очистные сооружения без изменений, поступают в водные объекты. Даже в небольших количествах они способны наносить существенный вред водным экосистемам и здоровью человека. Среди биогенных элементов, которые также присутствуют в сточных водах, наибольшего внимания заслуживают соединения азота и фосфора. Попадая в водные объекты, они служат причиной эвтрофикационных процессов, которые также являются опасными для экосистем и человека. Показано, что среди современного разнообразия методов очистки сточных вод наиболее перспективными для удаления фармацевтических препаратов и биогенных элементов являются биохимические методы и фотоочистные технологии, а также использование мембранных биореакторов. Биосорбционно-мембранные методы открывают возможности эффективного использования современных биотехнологий глубокого удаления биорезистентных ксенобиотиков и уменьшения их негативного воздействия на окружающую природную среду. Применение фотоочистных технологий позволяет уменьшить сброс биогенных элементов в поверхностные воды и тем самым уменьшить их потенциал эвтрофикации, а также получать дополнительные возобновляемые источники энергии. *Библ. 30, рис. 3, табл. 4.*

Ключевые слова: биорезистентные фармацевтические препараты, биогенные элементы, биосорбционно-мембранные методы очистки, фотоочистные технологии, сточные воды, мембранные биореакторы.