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PROJECT

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IMPROVEMENT OF DOMESTIC WASTEWATER TREATMENT SYSTEM

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Summary

Domestic wastewater is one of the main sources of pollution of aquatic ecosystems, which are the cause of the violation of the processes of self-regulation and self-renewal with the development of eutrophication of water bodies. Therefore, the issue of improving the approach to the system of domestic wastewater treatment is relevant for most localities of Ukraine.

The goal of the work is to improve the system of municipal treatment facilities aimed at stabilizing the process of domestic wastewater treatment.

The task of the research is to use the results of research to optimize the operation of plants of domestic wastewater treatment with the removal of nutrients.

The object of research is the municipal domestic wastewater treatment plants of Kamyanske. *The subject* of research is operation indicators of domestic wastewater treatment plants.

Objectives of the research: to analyze the process of wastewater treatment at the left-bank treatment facilities in Kamyanske; to monitor the operation of treatment facilities during the day and assess changes in the operation of facilities over the past decades; to investigate the effectiveness of domestic wastewater treatment with the removal of nutrients; to develop recommendations for stabilization of domestic wastewater treatment processes at Kamyanske treatment plants.

The practical value is in the proposed technical solutions to stabilize the processes of domestic wastewater treatment in order to reduce the content of nitrogen and phosphorus compounds at the treatment plants in Kamyanske.

Research methods are the methods of literature search and generalization in order to process literature data on wastewater treatment methods and ways to improve them; methods of determining daily costs and quality composition of domestic wastewater for nutrient content determined by approved standard methods; statistical research methods for analytical processing data using Microsoft Excel software.

Technical solutions for the stabilization of urban wastewater treatment processes to reduce the content of nitrogen and phosphorus compounds in treated wastewater are proposed.

Contents

Peremitko Iliia Valeriyovych was born in 2006. He is a pupil of the "Young Ecologists" group of the Children's Ecological Center of Kamyanske City Council, a student of 9-A form of the Technical Lyceum named after Anatoly Ligun of Dnipropetrovsk region Kamyanske City Council.

Ilya entered the municipal institution of the Educational Association "Lyceum of New Information Technologies - Comprehensive Educational Institution of I-II degrees - Preschool Educational Institution" of the Kamyanske City Council in 2013. Ilya Peremitko entered the Technical Lyceum named after Anatoly Ligun of Dnipropetrovsk region Kamyanske City Council in 2020 to continue his basic secondary education. While studying, he became interested in the environmental problems of the region and became a pupil of the "Young Ecologists" group of the Children's Ecological Center of Kamyanske City Council. Classes in the group encouraged Iliia to find ways to solve the problems of pollution of the Dnipro river basin.

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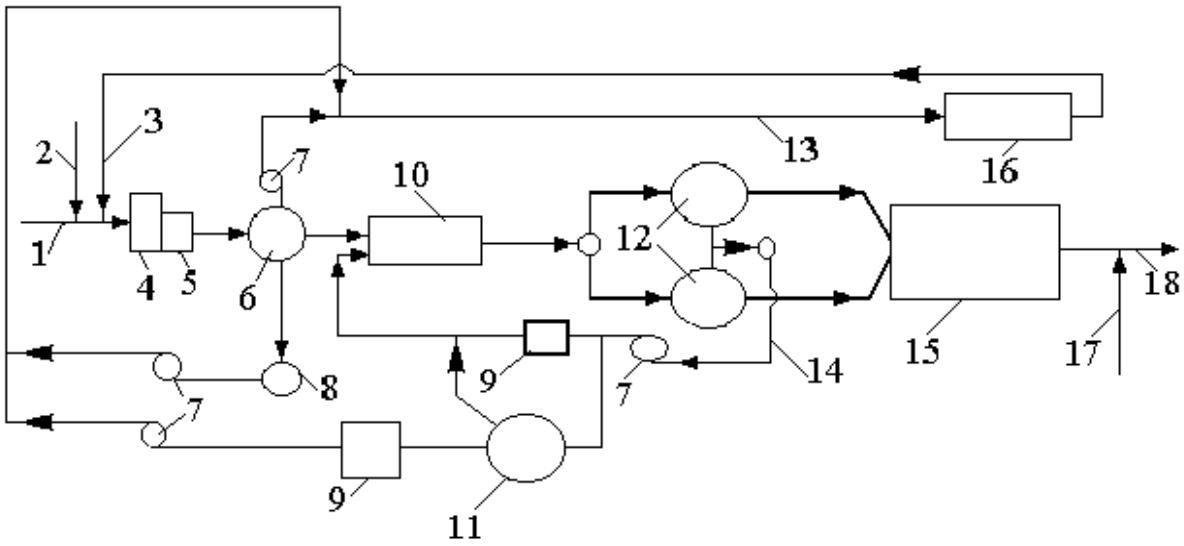
Introduction

From an ecological point of view, domestic wastewater is one of the main sources of pollution of aquatic ecosystems. They contain organic and inorganic substances that cause intensive anthropogenic pollution, including pollution by nutrients, when entering water bodies. As a result, the processes of self-regulation and self-renewal are disturbed in the reservoirs, blue-green and diamond algae and cyanobacteria, which are more adapted to such conditions, begin to dominate, and the process of eutrophication of reservoirs develops. During the "blooming" period, the pH of the environment (water) in the reservoirs increases and the content of dissolved oxygen decreases. It negatively affects the qualitative and quantitative composition of aquatic organisms and worsens the quality of surface waters. Therefore, the issue of improving the modern approach to the system of domestic wastewater treatment is relevant for most settlements of Ukraine.

1. Used materials and methods

The technological scheme of the left-bank wastewater treatment facilities in Kamyanske was used for the research. It is characterized by the fact that domestic wastewater (90%) is treated, and the rest is a mixture of industrial wastewater from the poultry farm, “Proton” plant, and a number of small commercial enterprises. The technological scheme of the left-bank treatment facilities and its description is shown in Figure 1.1.



1 - domestic wastewater; 2 - industrial wastewater; 3 - drainage water; 4 - lattice; 5 - horizontal sand traps; 6 - primary radial settling tank; 7 - pumps; 8 - fat collector; 9 - sludge tanks 10 - aeration tank; 11 - sludge compactor; 12 - secondary radial settling tanks; 13 - crude sludge and compacted sludge; 14 - activated sludge; 15 - biological ponds; 16 - sludge sites; 17 - chlorinated water; 18 - discharge of treated wastewater into the Dnipro River

Fig. 1.1. Flowchart of urban wastewater treatment (left bank of Kamyanske)

The designed capacity of the treatment plant is 100000 m^3/day and should have two lines with phased

commissioning: the first line was commissioned in 1979, and the commissioning of the second line was planned in the 90s of last century. However, political and economic changes in the country did not even allow the construction of the second line to begin, and later the need for its construction disappeared due to the reduction of the actual volume of wastewater. It is necessary to pay special attention to the fact that the built constructions are not designed for modern working conditions and requirements to qualitative indicators of the treated wastewater.

Wastewater treatment consists of the following stages: mechanical treatment (lattice, sand trap, primary settling tank); biological treatment (aerotank mixer, sludge compactor); post-treatment and disinfection (secondary settling tank, bio-ponds, and chlorination). The duration of mechanical treatment is 1,5-2 hours, the duration of wastewater in the aeration tank is 8-10 hours. The duration of settling at the stage of post-treatment is 1,5 - 2 hours, then the water is sent to bio-ponds, which occupy an area of 4 hectares and stay there for several days. The water is disinfected for 30 minutes before discharging into the Dnipro River. The time of water passage to the Dnipro should be at least 40 minutes. This time is required for the adsorption of chlorine ion on the surface of the residual amount of suspended solids.

2. Conducted research

2.1. Establishing compliance of the actual operation of treatment facilities with the designed indicators

It is determined that the actual capacity of treatment facilities is twice less than the designed one. Of the two primary settling tanks, only one is in operation and the other one is not loaded. When two secondary settling tanks are put into operation, there is a secondary pollution of treated wastewater in terms of ammonium nitrogen and phosphates due to the extra time of activated sludge in them - more than 4 hours instead of 1,5-2 hours provided by the project. The time of activated sludge being in regenerators is 16 hours, which is also 2 times higher than the regulatory conditions.

Therefore, first of all, it is necessary to significantly reduce the time of activated sludge being in secondary settling tanks and regenerators.

In order to provide proposals for improving the operation of the wastewater treatment system, a research on the cost loads on treatment plants was carried out. Hourly measurements of water that are treated during the day were made; the results are shown in Figure 2.1.

A comparative analysis of the operation of treatment facilities for 20 years has shown that the existing systems of domestic wastewater treatment have been subject to changes in the volume of load. In 2000 the volumes of wastewater treated exceeded the design capacity 1,3-1,5 times depending on the time of day, and now these volumes can reach only 10% of the designed capacity at night.

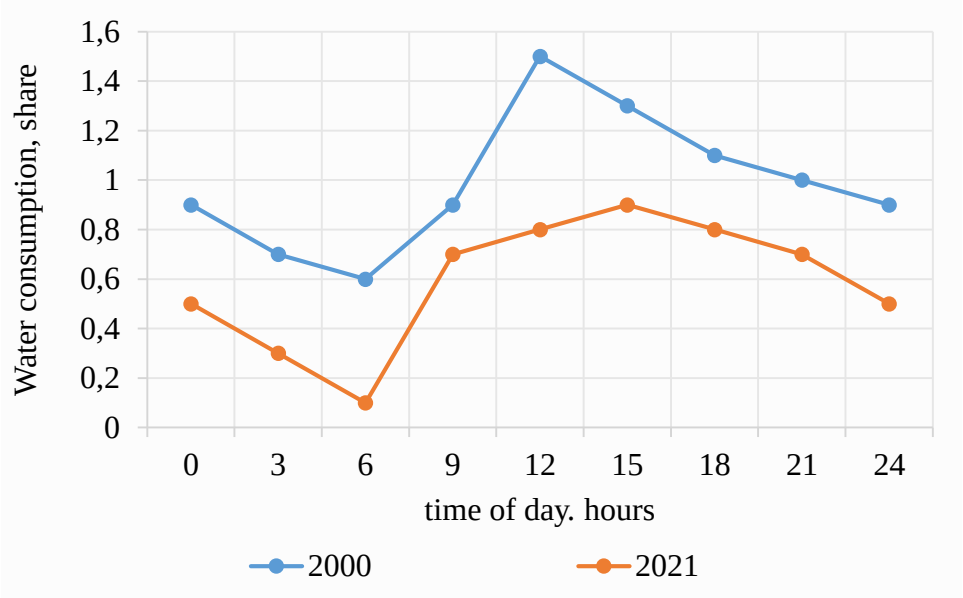


Fig. 2.1. Dynamics of wastewater supply to the left-bank treatment facilities in Kamyanske in 2000 and 2021.

2.2. The results of research on the qualitative indicators of wastewater

The quality of wastewater treatment was assessed by the content of nitrogen and phosphate compounds at the inlet and outlet of the treatment facilities of the left-bank wastewater treatment plant in Kamyanske according to the data of 2000. The results are shown in the diagram in Figure 2.2.

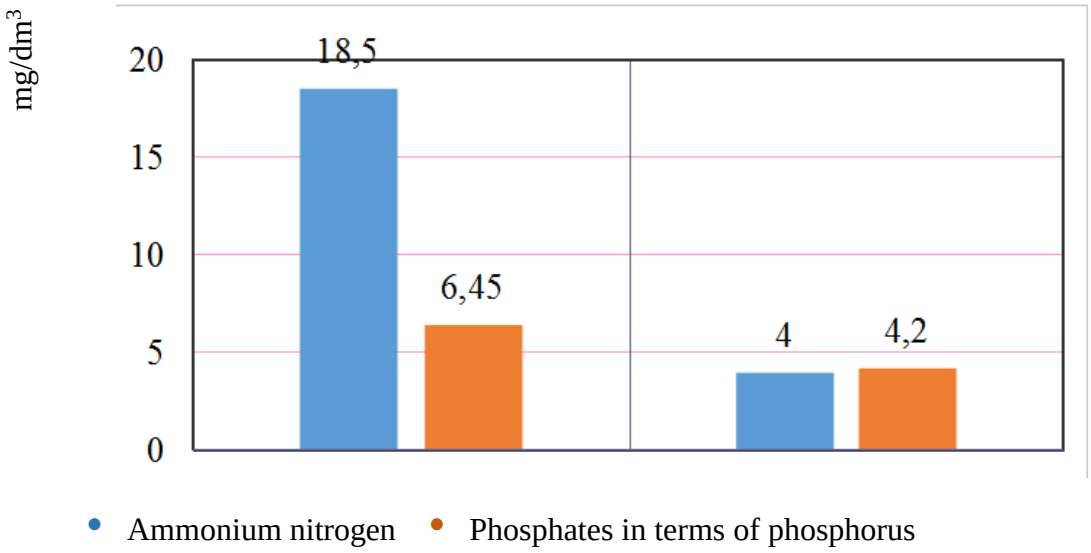


Fig. 2.2. Comparative qualitative composition of urban wastewater in terms of nitrogen and phosphate compounds at the left-bank treatment facilities in Kamyanske in 2001.

Based on the results of the quality of wastewater treatment, a significant decrease in the concentration of the studied indicators is determined. However, it should be noted that according to current legislation, the

maximum permissible concentration (MPC) of ammonium nitrogen is 0,5 mg/dm^3 for fishery water use, and for reservoirs of cultural and domestic water use this indicator may be 2,0 mg/dm^3; MPC of phosphates in terms of phosphorus is 0,17 mg/dm^3 for fishery water use, and 3,5 mg/dm^3 for cultural and domestic water use. That is, the quality of purification from nitrogen and phosphorus compounds is many times higher than permissible standards.

In order to determine the current state of wastewater treatment quality in 2021, a personal study of the content of nitrogen and phosphate compounds at the inlet and outlet of the treatment facilities of the left-bank wastewater treatment plant in Kamyanske was carried out.

Analytical control of wastewater quality indicators was carried out according to the established methods for accredited laboratories (KND 211. 1. 4. 030–95 and RND 09-05–2002). The analyzes are based on the photocolorimetric method, which consists in measuring the absorption of non-monochromatic light passing through the solution. The measurement was performed using a photoelectrocolorimeter – non-monochromatic radiation with a narrow wavelength range is obtained using light filters. According to these methods, a study of the content of nitrogen and phosphate compounds was made.

It is known that wastewater quality can vary depending on the time of day and season. Therefore, the content of nitrogen and phosphate compounds at the inlet to the treatment facilities of the left-bank wastewater treatment plant in Kamyanske was determined twice a day (at 8 am and 8 pm) for 10 days in March 2021. The results of the researches, averaged over 10 days, are shown in Table 2.1, indicate the daily instability of the quality composition of wastewater during the day. It was found that the highest concentrations of ammonium nitrogen and phosphates are observed in the second half of the day with mass water use; that confirms the results of studies of daily wastewater consumption shown in Figure 2.1.

Table 2.1. The average composition of wastewater for 10 days in terms of ammonium nitrogen and phosphate content at the inlet to the treatment plant depending on the time of day

Indicator	The content of compounds in wastewater, mg/dm^3	
	8th hour	20th hour
Ammonium nitrogen	33,4	42,1
Phosphates in terms of phosphorus	12,3	15,8

A study of the quality of wastewater at the inlet and outlet of the treatment facilities of the left-bank wastewater treatment plant in Kamyanske in accordance with the season during 2021 was carried out, too. The research results are shown in table 2.2.

Table 2.2. Comparative qualitative average composition of urban wastewater in terms of nitrogen and phosphate compounds during 2021

Substance	Place of sampling	The content of compounds in wastewater, mg/dm^3				Average value
		Winter	Spring	Summer	Autumn	
Ammonium nitrogen	inlet	46,2	48,7	49,8	47,7	48,1
	outlet	6,8	7,1	7,7	7,2	7,2
Phosphates in terms of phosphorus	inlet	16,9	17,3	19,6	17,8	17,9
	outlet	7,7	8,1	9,3	8,5	8,4

The results of the research shown in Table 2.2 demonstrate about insignificant fluctuations during the season in the content of nutrients in urban wastewater. The lowest content of nitrogen and phosphate compounds was observed in winter. At the same time, there is a proportional dependence of the reduction of the content of pollutants in the treated wastewater on the quality indicators that are detected when entering the treatment system. Thus, the stable imperfection of the existing wastewater treatment system at the left-bank treatment facilities in Kamyanske during the study period was determined.

In order to identify the causes of imperfections in the operation of treatment plants, a comparison of the average annual content of nitrogen and phosphate compounds in 2000 and 2021 was carried out. The results are shown as a diagram in Figure 2.3.

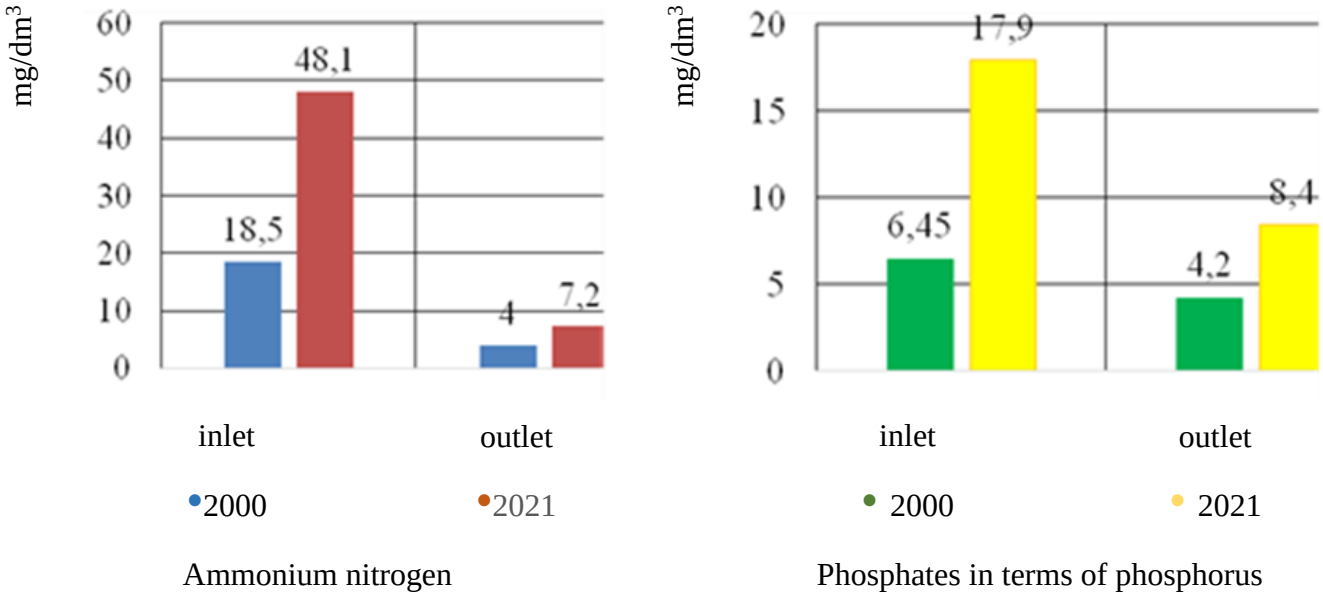


Fig. 2.3. Comparative qualitative composition of urban wastewater in terms of nitrogen and phosphate compounds at the left-bank wastewater treatment plants in Kamyanske in 2000 and 2021.

According to the results, it was determined that over the last 20 years there has been an almost threefold decrease in the quality of wastewater entering the left-bank treatment facilities in Kamyanske. This is the main reason for the decrease in the quality of treated wastewater discharged into the Dnipro River on the background of obsolescence and physical wear of equipment of treatment facilities and the lack of technological innovations of the treatment system as a whole. Apart from obsolete equipment, there are no modern methods of continuous quality and quantity control of wastewater. The problem of replacing obsolete equipment with new ones and restoring the means of control and automatic process control is long overdue.

According to the existing technology, with constant daily fluctuations of wastewater volumes, it is impossible to reduce the final content of ammonium nitrogen and phosphates in wastewater at the Kamyanske treatment plant due to unstable operation for the biocenosis, which is constantly in the mode of volley pollutants. Uneven supply of wastewater to aeration tanks leads to the formation of stagnant zones due to low circulation of activated sludge.

3. Obtained results

Daily fluctuations in wastewater supply to treatment facilities are quite significant, as shown in Figure 2.1, which negatively affects the operation of the entire treatment system. This actually stops the biological treatment process as the water supply is almost stopped at night. Accordingly, at night the time of water being in aeration tanks in conditions of "hunger" increases - activated sludge is significantly deficient in nutrients, and the time of water being in settling tanks increases with a constant decrease in dissolved oxygen causing secondary water pollution.

It is proposed to improve the technological scheme and mode of operation of treatment facilities. The technological scheme of the proposed technical solutions is shown in Figure 3.1.

The proposed improved scheme is based on the proposal to regulate the time of wastewater being in secondary settling tanks (12) by returning part of the water to the aeration tanks (10) with a critical reduction in wastewater supply to treatment plants. This will increase the stability of the main indicators of the quality of treated wastewater during the day.

The proposed technological solution will not stop the spontaneous flow of the purification process; it will help to eliminate secondary water pollution due to anaerobic processes and reduce soluble oxygen in water.

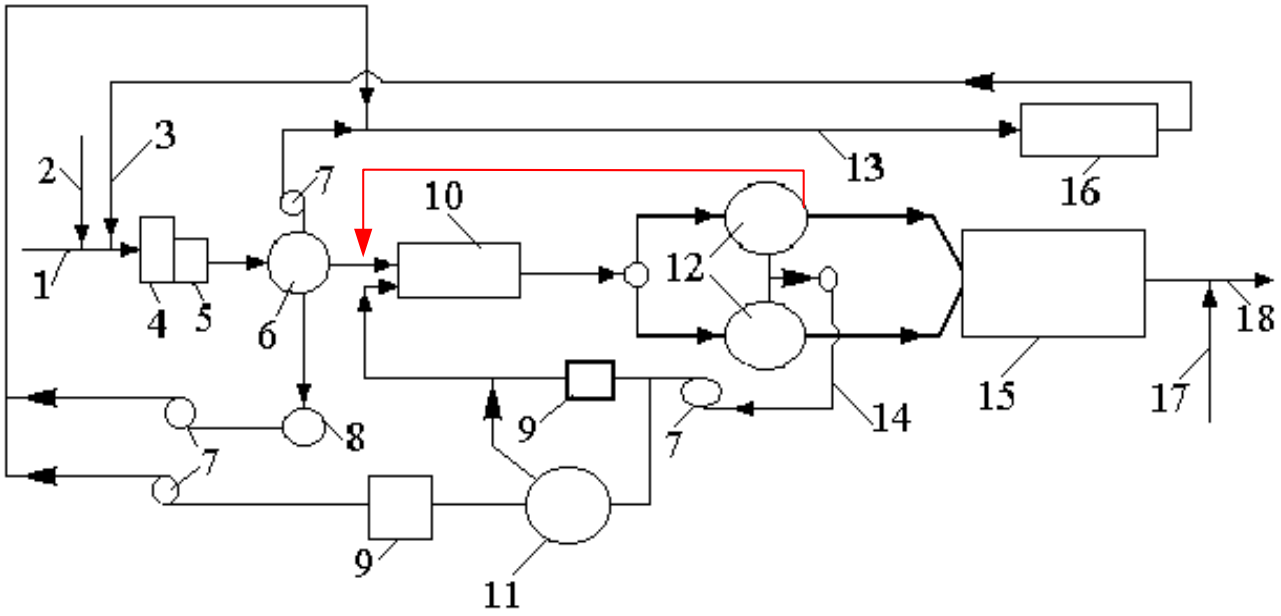


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Fig. 3.1. Improved flowchart of urban wastewater treatment (left bank of Kamyanske)

4. Analysis of similar studies in the world

4.1. Methods of wastewater treatment

Most cities in Ukraine have typical treatment facilities which consist of the main stages: mechanical treatment, physical and chemical treatment (if necessary), biological treatment; additional treatment and disinfection of biologically treated wastewater.

Traditional domestic wastewater treatment is a combination of physical and biological processes used to remove harmful substances from liquids.

Physico-chemical methods of wastewater treatment have a very limited use and are more often used for industrial wastewater treatment due to economic reasons. This method includes reagent purification, sorption, extraction, evaporation, degassing, ion exchange, electroflotation, electrodialysis, disinfection (ozonation, chlorination). The use of certain physico-chemical methods of wastewater treatment provides deep removal of contaminants; that eliminates the need for biological treatment [8].

The most rational in terms of economic and environmental criteria is the biological technology of urban wastewater treatment. The method of biological treatment is the most universal and widely used, but the low level of urban wastewater treatment is a significant disadvantage in modern conditions. The high

content of ammonium nitrogen and phosphates in treated wastewater is the reason of particular concern. The low level of purification from these compounds does not allow the reuse of treated wastewater without significant dilution with fresh water for industrial purposes [1-4]. Biological treatment technology is based on the use of microorganisms - aerobic or anaerobic bacteria. They are fed on organic matter present in wastewater. Contaminated water must be saturated with oxygen for aerobic bacteria to function.

Biological wastewater treatment actively implemented in utilities is able to retain phosphorus and nitrates contained in detergents and abstergents. Nitrogen and other harmful substances for humans and the environment contained in the products of human life are removed from the contaminated environment.

In the initial stages mechanical wastewater treatment, that is the removal of suspended and solid particles, is carried out. Next is physical and chemical cleaning - dissolved and suspended substances are retained. And only after that biological wastewater treatment is carried out, in the process of which up to 98% of organic pollutants are removed.

Existing biological treatment plants allow to treat wastewater from ammonium nitrogen compounds by only 20-60%, and phosphate compounds - by 10-20%.

The after-treatment system is a mandatory stage of wastewater treatment in cases where the treated wastewater replenishes the circulating water supply systems of industrial enterprises. Additional treatment facilities include ponds, filters with granular loading (sand, granite rubble, metallurgical slag, quartz, expanded polystyrene, etc.). Since the treatment processes use biological treatment methods using microorganisms, which may include pathogenic bacteria and viruses, the final stage of the process is the disinfection of treated wastewater. Disinfection can be reagent (with the use of oxidants) and non-reagent (ultraviolet radiation, ultrasound). The choice of water disinfection method depends on the cost and quality of water, efficiency and reliability of the process, conditions of supply and storage of reagents, process automation and feasibility study [4].

4.2. Ways to improve the wastewater treatment system

The solution to the problems of pollution of the Dnipro River basin is possible through the construction of the most advanced treatment facilities or the reconstruction of existing treatment facilities. In the period of reduction of funding for water protection measures and water conservation measures, the issue of improving existing treatment facilities by improving their mode of operation with minimal capital investment is especially relevant. The main requirement for advanced treatment facilities is to ensure the quality of treated wastewater that meets the standards for fisheries.

The introduction of new technologies for economic reasons is impossible, so it is advisable to reconstruct existing treatment facilities. Public utilities face the modern requirements for the quality of wastewater treatment; that is why the reconstruction of existing facilities using the technology of removal of nutrients is the best way.

A distinctive feature of wastewater discharged to municipal treatment plants is that they are largely free of large inclusions of mineral origin and heavily contaminated with organic matter. Therefore, there is a need for integrated construction of complex treatment plants that will provide indicators of the quality of treatment of organic compounds in accordance with the requirements.

Treatment of heavily contaminated wastewater has a number of features that significantly complicate the use of conventional methods for wastewater treatment containing organic impurities. Urban wastewater contains a wide range of organic carbon-, nitrogen- and phosphorus-containing pollutants, which are in a dispersed colloidal and dissolved state. These effluents are subjected to biological treatment methods, in the process of which the biochemical processes of oxidation of activated sludge by microorganisms are realized. The efficiency of biological treatment facilities (aeration tanks, biofilters, and secondary settling tanks) is determined by the concentration of contaminated wastewater that has previously undergone mechanical treatment.

Activated sludge is a living consortium with a complex structure. The biocenosis of activated sludge consists mainly of microorganisms associated with trophic and metabolic processes that result in wastewater treatment. Management of mixed cultures of microorganisms in the conditions of continuous processes of biochemical oxidation of organic pollutants is one of the promising ways to increase the biological activity and oxidative capacity of activated sludge microorganisms.

The urgency of the problem of intensification of biological wastewater treatment processes is indisputable, as the increase in technical and economic indicators of this method of treatment on a large scale of its application provides significant economic benefits. The method of biological treatment is the most universal and widely used, but the low level of urban wastewater treatment is a significant disadvantage in modern conditions.

Of particular concern is the high content of ammonium nitrogen and phosphates in treated wastewater. The low level of purification from these compounds does not allow to reuse treated wastewater without significant dilution with fresh water for industrial or agricultural purposes [1-4].

In recent years, there has been a tendency to reduce the amount of wastewater entering municipal treatment plants and increase the content of nitrogen and phosphorus in these effluents in the cities of Ukraine. This tendency is due to the fact that the population of cities is introducing drinking water meters in their homes, washing machines and dishwashers, which reduce the cost of drinking water while increasing the consumption of detergents. In addition, the creation of private industrial firms while closing many state-owned enterprises also saves drinking water. Therefore, the main problem in improving the existing treatment facilities of many cities of Ukraine is to increase the degree of treatment of urban wastewater from nitrogen and phosphorus.

Publications on the reduction of nitrogen and phosphorus in wastewater discharged into open water bodies are mainly limited to advertising low-capacity technology development by private firms, but the

problems of high-capacity treatment plants remain unresolved.

The urgency of developing and implementing new technical solutions for wastewater treatment is due to several reasons, among which the most significant are the following [9]: extremely limited funding for construction of new treatment plants and even increase maintenance of existing wastewater facilities; change in the requirements for the quality of treatment, especially in terms of reducing the concentration of compounds of nutrients in treated wastewater; the need to reduce energy costs for wastewater treatment dictated by rising energy prices; high (compared to developed countries) labor costs for the operation of wastewater treatment facilities; commissioning of new enterprises, in particular, the food industry.

Conclusions

In recent years, there has been a tendency to reduce the amount of wastewater entering municipal treatment plants and to increase the content of Nitrogen and Phosphorus compounds in these effluents. This trend is due to the fact that urban populations are introducing drinking water meters in their homes, which reduce the cost of drinking water while increasing the consumption of detergents. Therefore, the main problem in providing quality drinking water to the population and improving the existing treatment facilities in many cities of Ukraine is to increase the degree of treatment of urban wastewater from nitrogen and phosphorus.

According to the results of the study of the system of left-bank wastewater treatment plants in Kamyanske, it was determined:

1) the actual capacity of treatment plants is twice less than the designed one, which increases the time of activated sludge being in regenerators up to 16 hours, that is 2 times more than normal, and causes secondary water pollution due to anaerobic processes and reduced soluble oxygen in water;

2) the supply of wastewater to treatment plants is uneven during the day, which causes instability of nitrogen and phosphorus in wastewater at the inlet to treatment plants and adversely affects the quality of domestic wastewater treatment and leads to significant exceedances of MPC in treated wastewater;

3) to stabilize the operation of treatment plants regardless of the amount of wastewater entering treatment, it is proposed to return part of wastewater after the stage of treatment in secondary settling tanks to the beginning of the biological treatment process, which will help to equalize the flow of water and improve the quality of wastewater treatment from nitrogen and phosphorus compounds.

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